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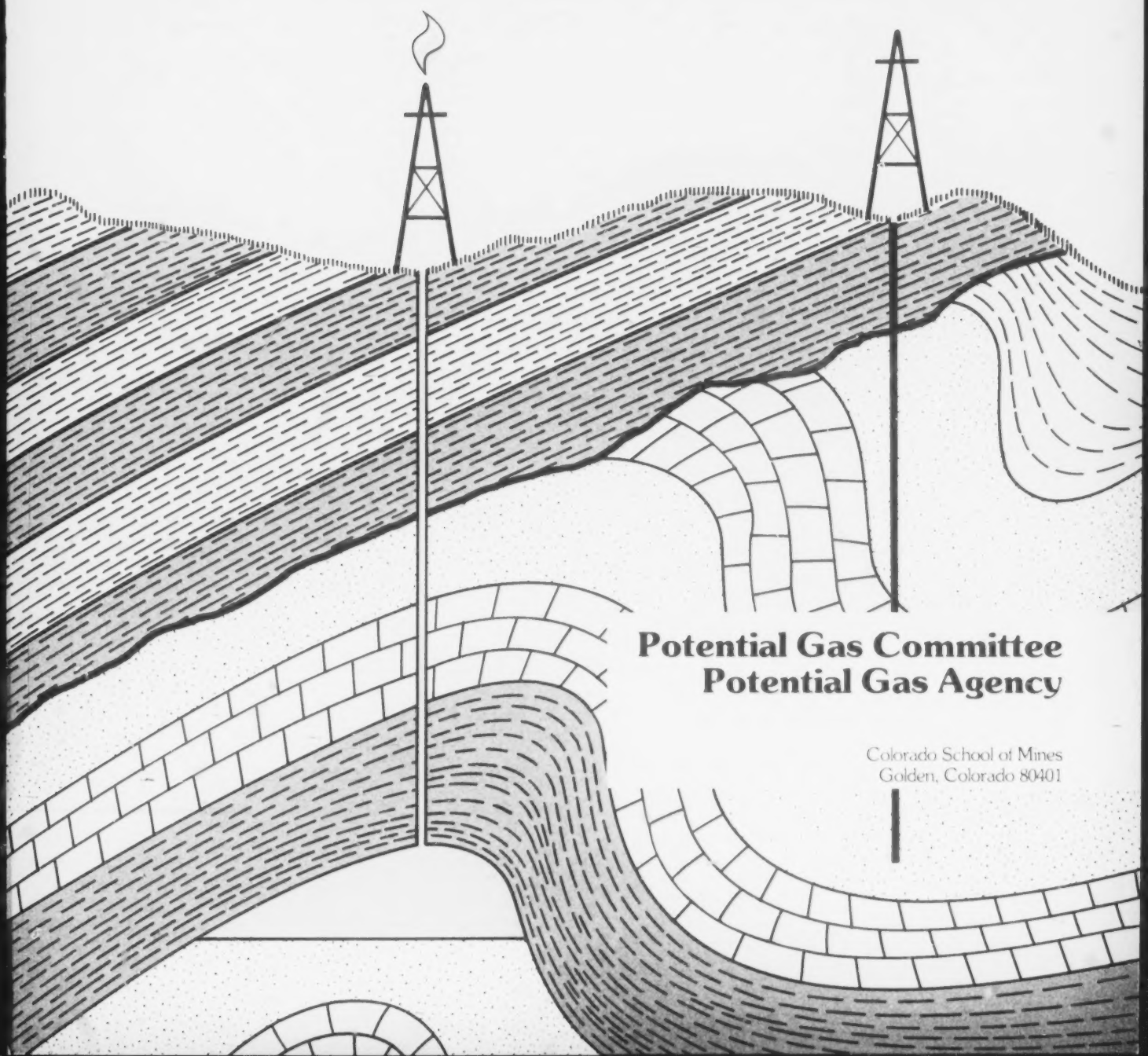
POTENTIAL SUPPLY OF NATURAL GAS IN THE UNITED STATES

(December 31, 1990)



Potential Gas Committee
Potential Gas Agency

Colorado School of Mines
Golden, Colorado 80401

The Potential Gas Committee consists of volunteer members from the natural gas industry, government agencies, and academic institutions who are concerned with natural gas resources.

The Committee functions independently but with the guidance and assistance of the Potential Gas Agency of the Colorado School of Mines. The Potential Gas Agency is supported by the American Gas Association.

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POTENTIAL SUPPLY OF NATURAL GAS IN THE UNITED STATES

(December 31, 1990)

Report of the Potential Gas Committee
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Potential Gas Agency
Colorado School of Mines

May 1991

Harry C. Kent

May 20, 1930 – April 16, 1991

Harry C. Kent dedicated his professional career to the creation and management of a scientifically based system for evaluating natural gas resources in the United States, and to the education and training of students of geology. Harry was a distinguished faculty member of the Department of Geology and Geological Engineering at Colorado School of Mines since 1956 and served as Department Chairman from 1970 to 1975. As a scientist and educator, he was unusually devoted to and caring of his students, always available to share his time, intellect, and experience for their benefit. His avocations were closely tied to his professional contributions in the fields of energy resource assessment, history of geological concepts, and micropaleontology.

As Director of the Potential Gas Agency from 1976 to 1991, Harry was tireless in his endeavor to place natural gas estimation techniques on a sound scientific basis, while recognizing the inherent difficulties in dealing with a natural system. Through the years, he was able to work effectively with members of the Potential Gas Committee as well as with many other colleagues in industry and government. His approach to resolving contentious issues through mediation rather than confrontation was a major factor in the evolution, wide acceptance, and usefulness of the work of the Potential Gas Committee. This report is evidence of his energy, his ability, and his dedication to the estimation of natural gas resources of the United States.

As an individual, Harry is and will be deeply missed by all who were fortunate to know him and work with him. He was an inspiration to all of us on the Potential Gas Committee over the past 15 years. It was his dedication more than any other factor that led to making our report more specific and useful with each printing. The best tribute that we, as members of this Committee, can pay to Harry is to dedicate this 1990 report in his memory and beyond this year to continue striving for improvement with each future report.

PREFACE

The objective of the Potential Gas Committee is to provide estimates, based upon expert knowledge, of the potential supply of natural gas which, in conjunction with estimates of proved reserves of natural gas, make possible an appraisal of long-range gas supply.

For many years, estimates of future supply of natural gas have been developed by numerous individuals and organizations. Since these estimates of future supply have varied widely and often have had entirely different objectives and meanings, they have served to confuse rather than to clarify the long-range outlook for natural gas supply. With the view to achieving a more unified industry-sponsored effort, many leaders of the natural gas industry, as well as various financial and governmental agencies, sought a longer-range, ongoing, study of the requirements and supply of natural gas in the United States. As a result of this concern, the work of the Potential Gas Committee was initiated in 1960. The Committee, in early years known as the Future Gas Supply Committee, has functioned since that time and has prepared regular reports presenting estimates of the recoverable natural gas which is believed to exist in addition to proved reserves. Since 1967 the work of the Committee has been guided and assisted by the Potential Gas Agency of the Colorado School of Mines.

Discussions of the geology and the natural gas potential are presented for each of the geographic areas included in 89 geologic provinces of the lower 48 states and Alaska. Fifty-five of these geologic provinces are in onshore areas and 34 are offshore. For each of the onshore provinces, separate estimates are given for (1) resources estimated to occur at drilling depths of less than 15,000 feet and (2) those estimated to occur at drilling depths between 15,000 and 30,000 feet. Offshore provinces are separated into those that occur beneath water depths of less than 200 meters (continental shelf) and those that occur beneath water depths of 200 to 1,000 meters (upper continental slope). A separate estimate is also reported for the territorial waters of the United States deeper than 1,000 meters in the Gulf of Mexico.

Resource estimates for each geologic province are given in terms of minimum, most likely, and maximum estimates. The Potential Gas Committee believes that this manner of reporting gives users an understanding of the uncertainty involved in the resource estimate for any one province. Resource estimates in this report are expressed in terms of billion cubic feet (Bcf) of estimated natural gas resource potential. The estimates are reported both as arithmetic sums of the most likely values and as the means of the statistically aggregated distributions.

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REPORT OF THE POTENTIAL GAS COMMITTEE

Summary

The Potential Gas Committee consists of volunteer members from all segments of the oil and gas industry, government agencies and academic institutions who are concerned with natural gas resources. This Committee has prepared and published biennial estimates of the potential supply of natural gas since 1964, with the exception of 1974. Members of the Committee, their experience and affiliations, are listed in the last section of this report. The Committee functions independently but with the guidance and assistance of the Potential Gas Agency of the Colorado School of Mines. The Potential Gas Agency is supported by the American Gas Association.

The Potential Gas Committee's estimates of the potential supply of natural gas in the United States, as of December 31, 1990, are shown in Table 1:

Table 1. Estimated potential natural gas resources
(billion cubic feet)

	Most Likely Values			
	Probable	Possible	Speculative	Total
Traditional Resources				
Lower 48 States				
--Onshore	133,354	177,184	116,657	427,195
--Offshore	23,110	61,550	65,500	150,160
Total Lower 48 States	156,464	238,734	182,157	577,355
Alaska				
--Onshore	31,250	16,400	27,700	75,350
--Offshore	2,400	12,700	53,000	68,100
Total Alaska	33,650	29,100	80,700	143,450
Total United States	190,114	267,834	262,857	720,805
Coalbed Methane	9,576	51,208	84,358	145,142
Grand total United States	199,690	319,042	347,215	865,947

The Potential Gas Committee has traditionally reported potential natural gas resources as the *most likely* estimate, the value of the mode of the statistical distribution of the estimated resource. The arithmetic sum of all of the *most likely* estimates of traditional resources as of December 31, 1990, is 720,805 billion cubic feet (Bcf). This value represents an increase of approximately two percent over the arithmetic sum of the *most likely* values of the December 31, 1988 resource estimates. In addition to estimates of traditional resources, the year-end 1990 Potential Gas Committee estimates also include a *most likely* estimate of recoverable coalbed methane of 145,142 Bcf.

These estimates represent the current status of a dynamic system in which former potential resources pass into Proved Reserves and ultimately into production through discovery and development of new pools and fields (Figure 1). Concurrently, the estimates of remaining potential resources are revised based on knowledge gained through additional exploration and drilling.

For the first time, the statistical distributions of the natural gas resource estimates have also been aggregated and reported as the *mean* values of the aggregations. The reasons for this approach are discussed on page 14. For year-end 1990, the *mean* value of the aggregated distributions of traditional resources is 855,329 Bcf, an increase of approximately two percent over the *mean* value of the statistical aggregation of the year-end 1988 estimates. A detailed comparison of 1988 and 1990 estimates is shown in Tables 6 and 8.

These estimates of the Potential Gas Committee represent the potential natural gas resources expected to be recovered by future drilling under conditions of:

1. adequate economic incentives in terms of price/cost relationships, and
2. current or foreseeable technology.

Estimates of the Potential Gas Committee are "baseline" estimates in that they attempt to provide a reasonable appraisal of the total natural gas resource potential of the United States and are not limited by assumptions of the time of development of the natural gas resource, the life span of the natural gas industry, or the specific price to be paid for the produced gas. There is no consideration of whether or not this resource will be developed; rather, the estimates are of the resource that could be developed if the need and economic incentive exist. Estimates also assume no governmental or regulatory restraints upon development and production of the resource.

The Potential Gas Committee's estimates do not include, and are distinct and separate from, the volume of proved recoverable natural gas reserves contained in the nation's discovered fields. Proved Reserves are reported by the American Gas Association Committee on Natural Gas Reserves and by the Energy Information Administration of the U.S. Department of Energy. The relationship between Proved Reserves and the several categories of potential natural gas resources is illustrated in Figures 1 and 2 and described in detail in the section on Categories of Natural Gas Resources.

A considerable portion of the change in resource estimates between succeeding biennial reports of the Potential Gas Committee is represented by the additions to Proved Reserves that have taken place in the preceding two years. Such reserve additions are estimated by PGC members based upon available data, and the additions are then removed from the appropriate resource categories. Decreases in estimates of Probable Resources occur because of field development and additions to reserves as a result of extensions of the producing area of the pool or field (Figure 1). Additions to estimates of Probable Resources are made based upon the undeveloped areas of fields that have been discovered and are under development at the time the resource estimates are prepared. Estimates of Possible resources are decreased based upon new field discoveries and increased when new provinces or formations are demonstrated to be productive of natural gas. Estimates of Speculative resources are reduced based upon new field discoveries and may be increased if new data indicate additional, previously unrecognized, potential for natural gas discoveries and production.

Major changes in resource estimates, especially estimates of Speculative resources, most frequently occur in frontier areas, such as some offshore regions, deeper portions of some onshore basins, Alaska, and portions of the Rocky Mountain states. These changes reflect the uncertainty of resource estimation where available geological and geophysical data are limited and where new exploration may bring about significant

changes in the knowledge and interpretation of the nature and occurrence of the natural gas resource.

In addition to expected changes resulting from potential resources passing into Proved Reserves, the following significant changes in resource estimates have been made:

Most of the increase in the Probable Resource category for the total United States can be attributed to a transfer of resources from Proved Reserves to Probable Resources for the North Slope of Alaska. These do not represent new resources but rather an accounting change by the companies producing oil and gas from the North Slope. This transfer amounts to approximately 24,600 Bcf. This move is in response to the actions of companies active on the North Slope who have removed a large portion of the Proved Reserves from their accounting. This action was taken in light of the fact that no transportation system exists to bring North Slope gas to market in the Lower 48 states. These changes in North Slope reserves are described in the report of the Energy Information Administration, *U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves, 1989 Annual Report.*[1]

Changes in the Gulf Coast Area primarily reflect transfers from potential resources to Proved Reserves as the result of continued drilling and discoveries. Poor wildcat success and the abandonment of offshore leases necessitated a reduction in the estimates of Possible and Speculative resources for the Eastern Gulf Offshore Shelf and Slope. A significant increase in the Speculative resource estimate resulted from incremental recovery anticipated with horizontal drilling of formations in the Texas Gulf Coast Basin.

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[1] Energy Information Administration, 1990, U.S. crude oil, natural gas, and natural gas liquids reserves, 1989 Annual Report: U.S. Department of Energy, Energy Information Administration [DOE/EIA-0216(88)] (and reports for earlier years), Washington, DC.

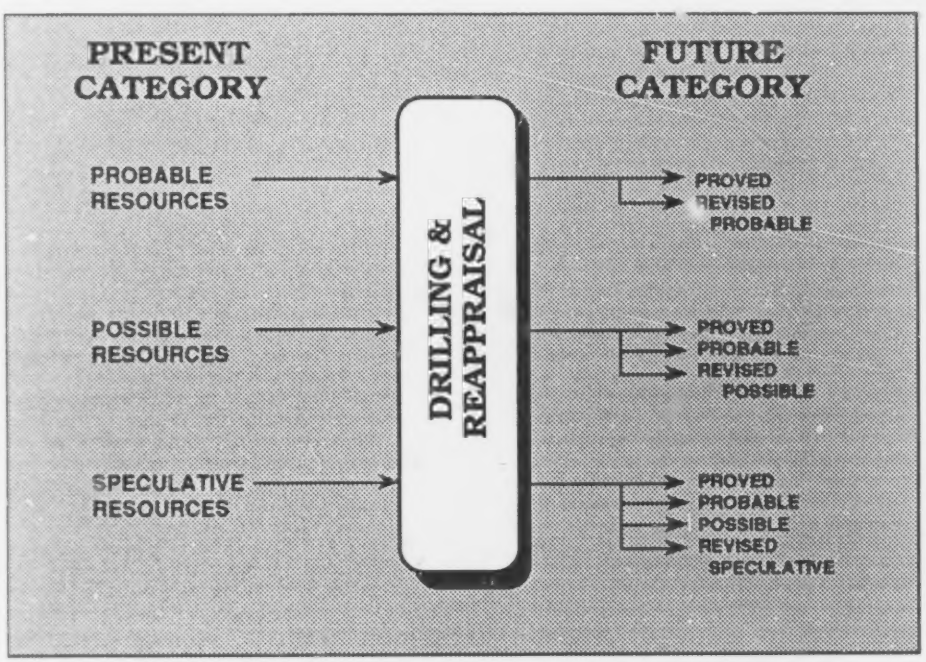

Figure 1. Schematic representation of progression of categories of potential natural gas resources as a result of drilling and reappraisal.

In the North Central Area, the Devonian Antrim Shale is being actively exploited as a shallow non-conventional gas resource in the north central part of the Michigan basin. Exploration of the Antrim has resulted in a significant increase in the most likely estimate of Potential gas resources. Recent evaluation of the Cambro-Ordovician data has resulted in a decrease in the most likely estimates.

Changes in the Rocky Mountain Area reflect activity in the Greater Green River and Wind River basins.

There have been no significant changes in resource estimates for the Atlantic, Mid-Continent and Pacific areas.

In addition to the two percent increase in *most likely* estimates of traditional resources, another major change has been the increase in estimates of recoverable coalbed methane. The increasing importance of coalbed methane makes more detailed analysis of this resource vital, since it is the subject of extensive current development. The current status of coalbed methane production is summarized in a separate chapter. High levels of activity in the San Juan and Black Warrior basins are now spreading to coal-bearing areas in the Appalachian and Illinois basins, southeastern Kansas (Cherokee basin); and to the Powder River, Hanna and Wind River, Wyoming; Greater Green River, Wyoming-Colorado; Piceance and Raton, Colorado; Uinta, Utah; and Puget-Willamette, Washington basins. The national *most likely* estimate is 145,142 Bcf for year-end 1990, a 61 percent increase over the comparable estimate for year-end 1988. This increase is due to the fact that 32 coal-bearing regions have been assessed, compared to five for the year-end 1988 report.

Introduction

The estimates of the Potential Gas Committee are of natural gas that, in the judgment of Committee members, can be recovered by conventional means given adequate economic incentives in terms of price/cost relationships and utilizing current or foreseeable technology. Since these potential resources have not yet been confirmed by drilling and testing, there can be no rigorous evaluation of the economic viability of the resources. The accumulations are, however, believed to exist in concentrations of sufficient size and quality, considering geographic distribution and depth of occurrence, to warrant exploration and development.

The Potential Gas Committee's estimates do not include proved reserves. Annual estimates of proved reserves of natural gas in the United States were prepared, from 1946 through 1979, by the Committee on Natural Gas Reserves of the American Gas Association. Currently that Committee publishes an annual report containing estimates of proved reserves for selected fields.[1] Since 1977, and continuing to the present, annual estimates of proved reserves have been prepared independently by the Energy Information Administration of the U.S. Department of Energy.[2] These estimates are, by definition, limited to those estimated proved recoverable reserves of natural gas that have been established by drilling. Such estimates do not reflect Potential Resources of natural gas that may be discovered as a result of future exploratory drilling. It is the estimates of Potential Resources that are the concern of the Potential Gas Committee and that are discussed in this report.

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[1] American Gas Association, Natural gas reserves of selected fields in the United States and of Canada prepared annually by the American Gas Association and the Canadian Petroleum Association.

[2] Energy Information Administration, 1990, U.S. crude oil, natural gas, and natural gas liquids reserves, 1989 Annual Report: U.S. Department of Energy, Energy Information Administration [DOE/EIA-0216(88)] (and reports for earlier years), Washington, DC.

Additionally, the Potential Gas Committee's estimates do not include natural gas that may be recovered in the future from sources not currently recoverable with existing technology and under current or foreseeable economic conditions. Examples of such sources not included are gas from hydrates, gas from geopressured-geothermal accumulations, deep-earth gas or gas contained in very low-permeability formations not recoverable with existing or foreseeable technology. As technology and economic conditions change, the Potential Gas Committee reviews its estimates and revises them as appropriate.

Definition of Natural Gas

Natural gas, as used in this report, is any gas (at standard conditions of temperature and pressure, 14.73 psia and 60°F) of natural origin that is composed primarily of hydrocarbon molecules producible from a borehole. Most natural gas contains some nonhydrocarbon components, such as carbon dioxide, nitrogen, hydrogen sulfide and helium. In estimating potential supply, it is not feasible to separate small volumes of these components from the hydrocarbons; however, in areas where significant volumes of such nonhydrocarbons are believed to occur, only the hydrocarbon components are included in the estimated potential supply.

Categories of Natural Gas Resources

A finite volume of natural gas in place exists within the rocks of the shallow portion of the earth's crust. This finite volume of gas in place is the total natural gas resource. The amount of this resource that is recoverable is a function of technology and economics. The categories of this resource are shown in Figure 2. Today, technology has advanced to the degree that a significant part of the natural gas resource base can be recovered. A major part of this resource, however, is dispersed throughout the earth's crust in such minute accumulations or under such conditions that it cannot be extracted with existing or foreseeable technology. Also, the cost of recovery of such gas would be too high compared to the value of the gas. Even with likely advances in technology, production of some deposits would not be feasible because recovery of such accumulations would require more energy than that provided by the gas produced. The recoverable resource is that part of the resource that is susceptible to discovery and production dur ng the life of the industry using current or foreseeable technology and under favorable price/cost ratios.

The above limitations of size of accumulation and economics are applied as follows. For situations in which a distribution of sizes of individual accumulations is envisioned (particularly in estimation of probable and possible resources, as described below), a minimum size of recoverable accumulation is determined on the basis of the estimator's current judgment of the relationship between the value of the resource and the cost of drilling and production. This relationship is based on extrapolation of the prevailing price/cost ratio at that time for the given geologic province and depth. This often takes the form of an estimate of the minimum recovery per well that is necessary in order for an operator to determine if a well is economically feasible to complete and produce in a given geographic area and depth. Such a well may not, in total, be an economically viable venture, but given that the well has already been drilled to the target, the available resource will be produced and will probably recover the costs of completion and production, even if the total costs of exploration and drilling are not recovered. At the other end of the size and economic spectrum, a maximum size of accumulation is determined on the basis of the estimator's evaluation of the geologic factors controlling the size and effectiveness of traps and the reservoir conditions.

The size and economic limitations are evaluated in a more general way in situations in which it is not possible to estimate the number and sizes of individual accumulations. This is particularly the case in the estimation of speculative resources (as discussed below). In these situations, analogies are made with provinces or formations in which natural gas production has already been established and have similar geologic characteristics to the unexplored province or formation. It is hoped that, if these analogies are drawn carefully and accurately, analogous conditions of size and economics will also apply.

The Recoverable Resource is composed of both discovered and undiscovered natural gas resources. Discovered gas consists of the quantity produced in past years plus that proved by drilling and engineering tests and included in present Proved Reserves. Discovered gas also includes the gas remaining in known fields that will be recovered through extension and complete development of known pools and reservoirs. The undiscovered resource consists of the potential gas supply that could become productive with further exploration and development. The undiscovered resource includes both the gas remaining in undiscovered pools and reservoirs within known fields and the gas that may be discovered in new fields and reservoirs within geologic provinces that are presently productive and those as yet unproductive.

The subdivision of the recoverable resource into categories reflects the variation in the amount of geologic and engineering information on which the estimate is based. These categories are independent of any interpretation of the cost of development and production of the gas. Proceeding from left to right in Figure 2, the level of geologic and engineering knowledge decreases.

Cumulative production is the total volume of natural gas that has been withdrawn from producing reservoirs. Some uncertainty involving the amount of production from earlier years exists as a result of incomplete records, but a reasonable estimate has been made based on available information. Estimates of past production presented in this report have been prepared by the Committee on Natural Gas Reserves of the American Gas Association (CONGR). Annual production for years through 1979 was obtained from the reports of CONGR.[3] Annual production for years from 1980 to the present was obtained from reports of the Energy Information Administration (EIA) of the U.S. Department of Energy.[4]

Proved Reserves are the currently estimated quantities of natural gas that analysis of geologic and engineering data demonstrate with reasonable certainty to be recoverable in the future from known oil and gas reservoirs under existing economic and operating conditions. Reservoirs are considered proved that have demonstrated the ability to produce by either actual production or by conclusive formation tests. The existence and quantity of gas have been *confirmed* by testing. The PGC does not estimate volumes of proved reserves. Estimates of proved reserves were compiled annually from 1946 through 1979 by the Committee on Natural Gas Reserves of A.G.A. (CONGR).[5] The A.G.A. estimates have been largely supplanted by reports prepared by EIA which began with data for 1977 and have replaced the A.G.A. estimates for 1980 and subsequent years.[6]

There are differences in definition of proved reserves used by various reporting organizations as well as by individual companies. Definitions adopted by the Society of Petroleum Engineers[7] restrict proved reserves to reserves that are supported by actual production or formation tests and by extrapolation of such tests to both drilled and undrilled locations. Proved reserves are further restricted to those commercially recoverable and marketable under existing economic conditions at the time of the estimate. There must also be operational facilities to process and transport the reserves to market or a commitment to install such facilities. Under these new definitions, and with the economic conditions prevailing in the natural gas industry in recent years, companies have removed some reserves from the category of proved reserves. This has been particularly apparent in Alaska, where considerable quantities of reserves on the North Slope have been so removed. Other reporting organizations, notably EIA and CONGR, have exercised more latitude in the application of economic yardsticks and the installation of processing and transport

[3] American Gas Association, 1980, Report of the Committee on Natural Gas Reserves, *in* Reserves of crude oil, natural gas liquids, and natural gas in the United States and Canada as of December 31, 1979: American Petroleum Institute, American Gas Association, and Canadian Petroleum Association, 253 p. (also annual reports for preceding years), Washington, DC.

[4] op. cit.

[5] op. cit.

[6] op. cit.

[7] Approved by the Board of Directors, Society of Petroleum Engineers (SPE), Inc., February 27, 1987.

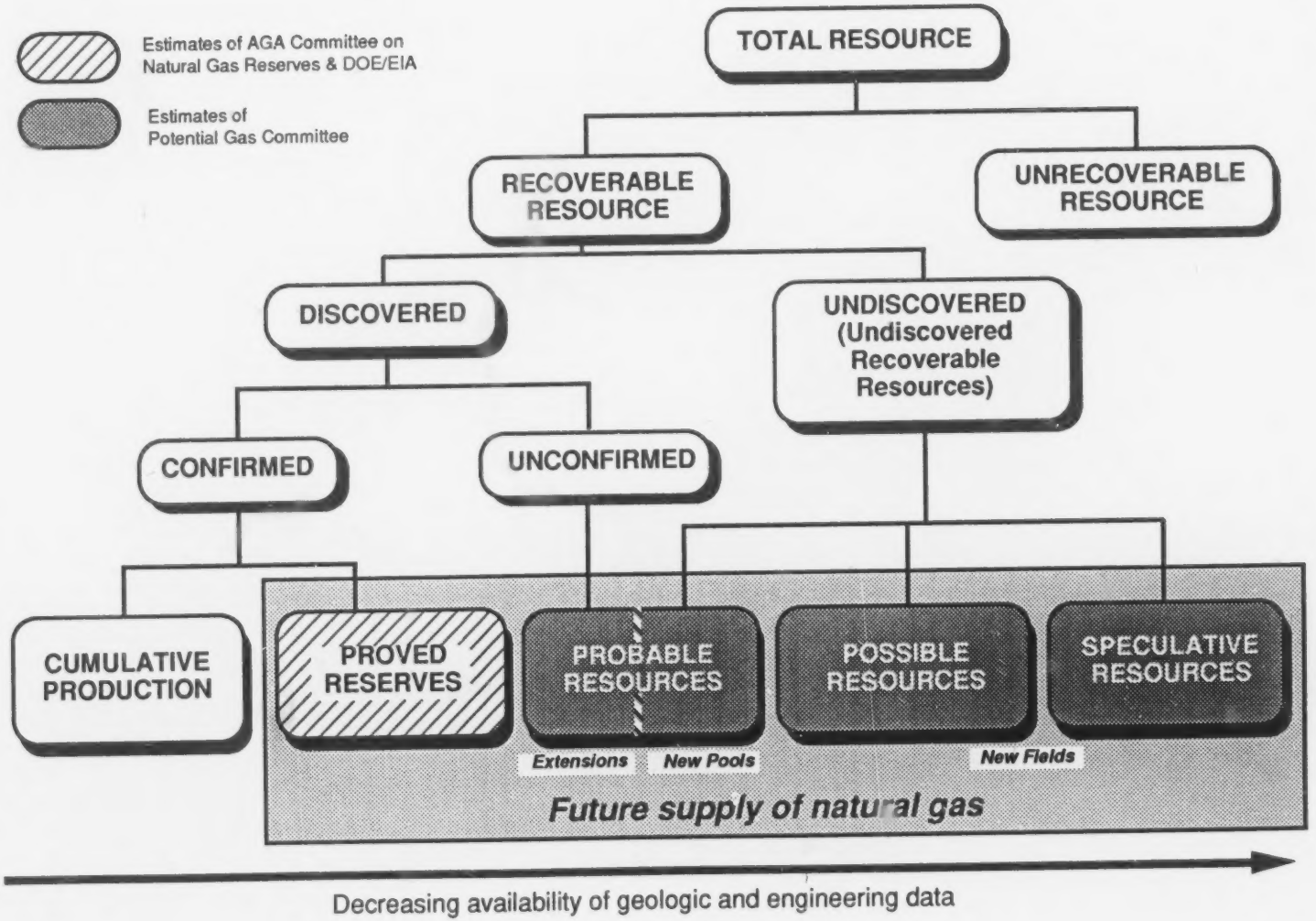

Figure 2. Natural gas resource categories.

facilities and have retained estimates for proved reserves on the North Slope of Alaska. This has left the status of some proved reserves uncertain. Since the Potential Gas Committee attempts to make certain that its estimates coordinate with those of EIA and CONGR, it has included in its estimates, as Probable Resources, those proved reserves previously included in EIA and CONGR reports. A note has been added to the resource estimates for Alaska to draw attention to this matter.

Potential resources. The estimates of the PGC include all the undiscovered resource plus the portion of the discovered gas resource that is not included in proved reserves (shaded areas in Figure 2.) Three categories of potential resources are recognized and reported by the PGC: Probable, Possible and Speculative. These three categories are differentiated on the basis of variation in available geologic, geophysical and engineering information. Estimates of both nonassociated and associated or dissolved gas are included in all categories.

Limitations to the estimates have been established by the PGC on the basis of current technological capabilities and an estimate of the expansion of those capabilities in the foreseeable future. No estimate is made for onshore areas of natural gas that might exist at drilling depths in excess of 30,000 feet. Estimates for onshore areas are also made for two depth intervals, 0-15,000 feet and 15,000-30,000 feet, in recognition of the greater costs and technical requirements for wells drilled below 15,000 feet. No estimate is made for offshore areas of any natural gas that might exist beneath water depths greater than 1,000 meters except for the Gulf of Mexico. Also, separate estimates are made for offshore areas of resources below water depths of 0-200 meters and depths of 200-1,000 meters, respectively, because of the higher costs associated with drilling platforms, production facilities and pipelines in deeper water. For the Gulf of Mexico, an additional province incorporating United States territorial waters deeper than 1,000 meters has been included.

Probable resources are associated with known fields and are the most assured of potential supplies. A relatively large amount of geologic and engineering information is available to aid in the estimation of the resource existing in this category. Probable resources bridge the boundary between discovered and undiscovered resources. The discovered portion includes the supply from future extensions of *existing pools* in known productive reservoirs [1].* The pools containing this gas have been discovered, but their extent has not been completely delineated by development drilling. Therefore, the existence and quantity of gas in the undrilled portion of the pool are as yet *unconfirmed.* The undiscovered portion is expected to come from future *new pool* discoveries within existing fields either in reservoirs productive in the field [2], or in shallower or deeper formations known to be productive elsewhere in the same geologic province or subprovince [3].

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* Numbers in brackets refer to accumulations shown diagrammatically in Figure 3.

Explanation for Figure 3—Schematic representation of categories of potential resources

I. Probable resources—Associated with existing fields, most assured,
   1) Discovered—unconfirmed: discovered trap, existing production elsewhere in the trap [1]
   2) Undiscovered: undiscovered trap, productive formation—supply from new pool discoveries within existing field in
      a) reservoir producing within the same field [2]
      b) shallower or deeper formations producing elsewhere within same geologic province or subprovince [3]

II. Possible resources—Associated with productive formations, less assured,
   1) Similar geologic conditions [4]
   2) Different geologic conditions: e.g., stratigraphic vs. structural trap [5]

III. Speculative resources—Most nebulous
   1) From nonproductive formation in productive province
      a) new pool [6]
      b) new field [7]
   2) From nonproductive province [8]

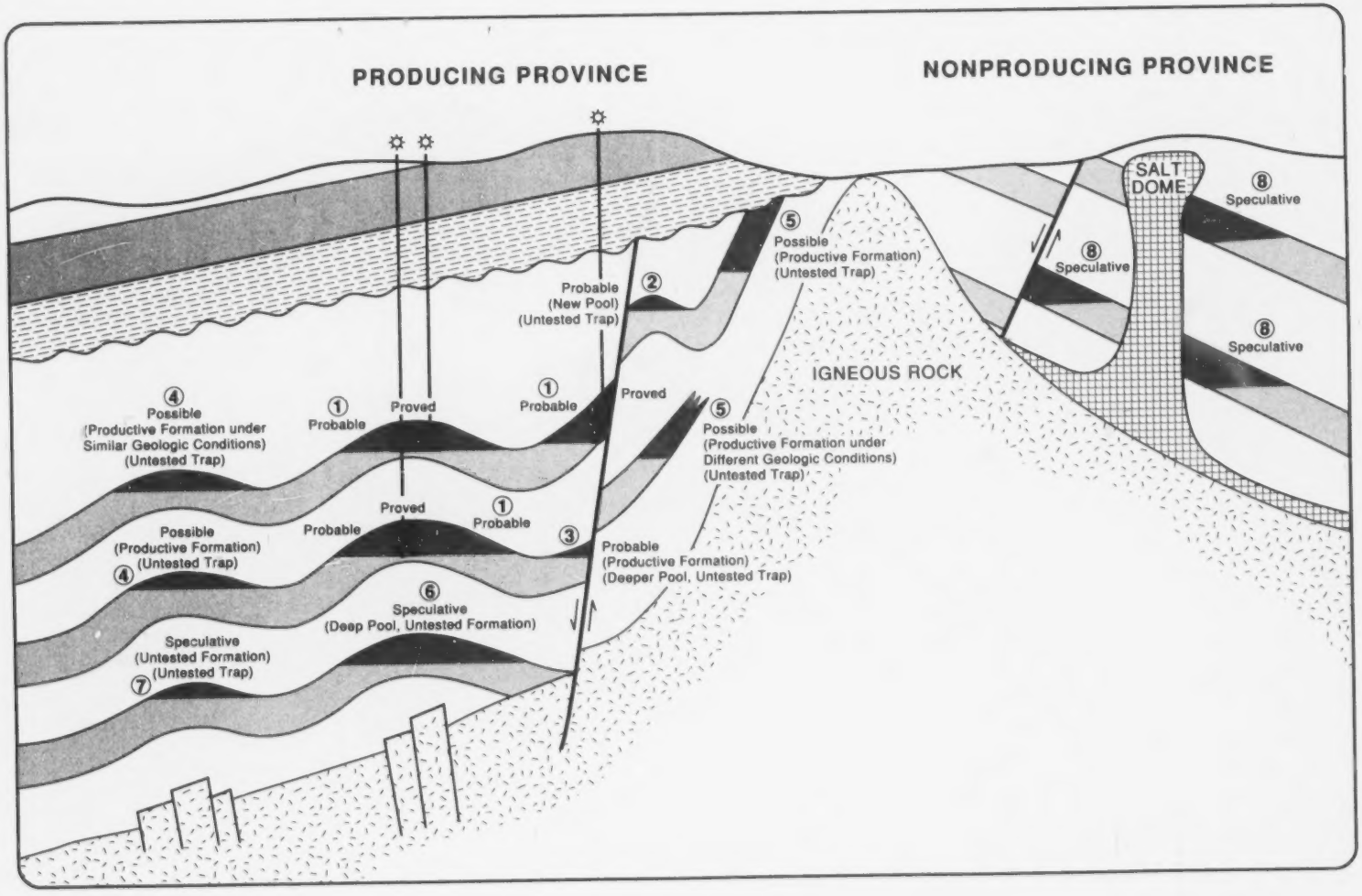

Figure 3. Schematic representation of categories of potential gas resources.

Possible potential resources are a less assured supply because they are postulated to exist outside known fields, but they are associated with a productive formation in a productive province. Their occurrence is indicated by a projection of plays or trends of a producing formation into a less well-explored area of the same geologic province or subprovince. The resources are expected to be found from *new field* discoveries, postulated to occur within these trends or plays under both similar [4] and different [5] geologic conditions (i.e., the types of traps and/or structural settings may either be the same or different in some aspect).

Speculative resources, the most nebulous category, are expected to be found in formations or provinces that have not yet proven productive. Geologic analogs are developed in order to ensure reasonable evaluation of these unknown quantities. The resources are anticipated from *new pool* [6] or *new field* [7] discoveries in *formations not previously productive* within a productive geologic province or subprovince and from *new field* discoveries within a geologic *province not previously productive* [8].

To reiterate, the accuracy of the estimates of potential resources of natural gas is dependent upon geologic conditions and upon knowledge of those conditions and the extent to which the given area has been explored and developed. The consistency and compatibility of the estimates by members of the Potential Gas Committee are maintained by following the estimation guidelines as closely as possible. However, the individual estimator may have to use slight modifications of the considerations and procedures when compiling estimates for each of the three categories because of the particular characteristics applicable to his reporting area.

Estimation of Potential Gas Supply

Geologic provinces and work areas

A total of 89 standard geologic provinces has been defined by the Potential Gas Committee (PGC) (Fig. 4, page 12; Plates 1 and 2). The boundaries of these provinces in the conterminous United States correspond closely to geologic province boundaries established by the Committee on Statistics of Drilling (CSD) of the American Association of Petroleum Geologists. In some instances, adjacent CSD provinces have been combined by the PGC where these provinces have only limited potential for natural gas resources. The province boundaries conform closely to geologic boundaries recognized by the working geologists of the PGC and have the advantage of accessible drilling, discovery and geologic information for the province. Minor changes to province boundaries have also been made where, in the judgment of PGC members, geologic conditions required modification. Provinces for Alaska have been established independently by the PGC on the basis of current understanding of geology and resource potential and do not correspond to provinces established by the CSD. Resource estimates are made for each geologic province by members of the PGC.

For purposes of organization, the PGC is subdivided into seven Area Work Committees that correspond to geographic areas of the country. Each area contains a number of geologic provinces, and each committee is responsible for preparation of the resource estimates for the geologic provinces that fall within that area's limits. Membership for the Area Work Committees is recruited from among geologists and engineers who are actively engaged in exploration and development of natural gas in the various geologic provinces. Since the judgment of the estimator is the most significant single factor in the preparation of resource estimates, every effort is made to recruit the most knowledgeable experts for membership. Additionally, a separate committee has been formed to prepare a report on resources of natural gas recoverable directly from coal seams. This report is included as a separate chapter in this publication. Although understanding of the nature

of the coalbed methane resource is incomplete and production history is limited, commercial recovery is taking place and the resource is being recovered. The relative immaturity of the coalbed methane industry and lack of long-term production records of key gas-content and coal reservoir characteristics in many areas make it difficult to prepare estimates of recoverable quantities of gas; however, the chapter summarizes the current state of knowledge.

Estimation procedures

This section presents a brief review of the techniques used by the Potential Gas Committee in preparing estimates of the natural gas resources of the United States. More detail concerning the methodology and its application is contained in the procedures manual of the Potential Gas Committee.[1]

The basic technique for estimation of potential gas resources is to compare the factors that control known occurrences of natural gas with factors present in prospective areas. This attribution technique is applied to each of the categories adopted by the PGC. In each case, what is known about the prospective area is evaluated relative to what is known about natural gas accumulations that have been discovered in other parts of the same geologic province or in similar geologic provinces. Natural gas occurrences are related to conditions favoring their formation and accumulation, such as the existence of source rocks, sufficient maturation of organic material, and the presence of reservoir rocks and traps. Studies of producing areas provide information on the productive capacity of particular formations and the average size of accumulations. In its simplest form, the estimate of the potential supply is derived by (1) estimating the volume of potential gas-bearing reservoir rock, (2) multiplying this volume by a yield factor,[2] and (3) discounting to allow for the probability that the traps and/or the accumulations exist. Modifications of the basic technique are necessary to accommodate the variations in amount of information available for prospective areas.

The judgment of the estimator is the most significant factor in making estimates of potential supply, particularly in determining the three categories of *Probable*, *Possible* and *Speculative* resources. Estimators must make the necessary judgment concerning the extent and number of traps, reservoir conditions, probability of the existence of traps and the probability of trap fill, and economic probability of accumulations and their sizes. Due to the wide variation in trends, plays, trapping mechanisms, geographic distribution of source rocks, characteristics of potential reservoir rocks, recovery and yield factors and the areal extent of basins, different approaches and modifications of the basic technique of resource analysis are employed by each estimator. These judgments must necessarily be based on the experience of the estimator and the data available. Members of the Potential Gas Committee, having the detailed knowledge and experience necessary to select the appropriate adjustments for an assigned geologic province, use all available geological and engineering data, both public and proprietary, in applying an objective, scientific approach to the problem of resource estimation.

Each estimator considers three separate situations in preparing estimates:

1. The existence of the minimum number of traps, the most marginal of source bed and reservoir conditions, the minimum reasonable yield factor and the possibility that many traps that might exist would not contain recoverable accumulations of natural gas. In this case, there is approximately a 100 percent probability that at least this much gas resource is present. Such conditions would lead to a ***minimum*** *(100 percent probability) estimate of the resource.*

[1] Potential Gas Committee, 1990, Definitions and procedures for estimation of potential gas resources: Gas Resources Studies Number 3, Potential Gas Agency, Colorado School of Mines, Golden, CO, 44 p.

[2] Yield factors represent the amount of gas expected to be produced from a given unit volume of rock. They are calculated using data from known gas accumulations considered most similar to the one being evaluated. The yield is the volume of discovered gas (i.e., cumulative production plus proved reserves) divided by the volume of productive rock containing the discovered gas. The yield factor applied to any prospective area is adjusted to accommodate variations appropriate to the prospective area.

Figure 4. Potential Gas Committee work areas and geologic provinces.

2. The most reasonable estimate of the existence of traps and accumulations and the most reasonable assessment of the source bed, yield factor and reservoir conditions. There is the highest probability that these conditions would prevail in the judgment of the estimator and that the estimated quantity of natural gas resources would be present. Such conditions would lead to the ***most likely*** *estimate of the resource.*

3. The quantity of gas that might exist and be recoverable under the most favorable conditions. The probability that such conditions might prevail is close to zero, and there is a very low probability (essentially zero) that this much gas resource is present. This assumes a maximum number of potential traps with favorable source bed and reservoir conditions, the maximum reasonable yield factor and each trap filled with recoverable accumulation. Such conditions would lead to the ***maximum*** *possible resource estimate.*

Estimates of the minimum, most likely and maximum resource potential are given individually for each geologic province. Resource estimates for each province are then used to derive a total resource potential for each Area and for the entire nation.

By considering each of the three situations outlined above, the estimator can best express both the limiting conditions within the geologic region and also the most likely estimate of the resource potential. Estimates prepared by the individual estimators are reviewed periodically at meetings of Area Work Committees and by the entire PGC at the national level, in order that a reasonable degree of consistency and uniformity is maintained.

Limiting Considerations

The estimates presented here are limited to the contiguous United States, Alaska, and adjacent offshore areas. Hawaii, the island territories and their adjacent offshore areas are not included.

Potential Gas Committee Work Areas and geologic provinces for the Lower 48 states are shown in Figure 4, page 12, and on Plate 1. Alaskan provinces are shown generally on page 120 and on Plate 2.

Drilling depth and water depth limitations

No potential supply of natural gas is included that exists at subsurface depths greater than 30,000 feet or, in offshore areas, where water depths exceed 1,000 meters (3,281 feet), with the exception of the Gulf of Mexico where estimates are included for water depths greater than 1,000 meters in United States territorial waters. Separate evaluations are made for the potential supply existing at onshore drilling depths from 0 to 15,000 feet and from 15,000 to 30,000 feet. These subdivisions recognize the greater technological and economic difficulties of recovering resources that exist below drilling depths of 15,000 feet. In offshore areas, estimates are made for the potential existing beneath water depths of 0 to 200 meters (656 feet) and 200 to 1,000 meters (3,281 feet). In the Gulf of Mexico, a separate estimate has been made for water depths greater than 1,000 meters. Estimates for water depths less than 200 meters essentially represent the potential supply that may be recovered from beneath the Continental Shelf, whereas the estimates for water depths of 200 to 1,000 meters essentially represent resources that may be recovered from beneath portions of the Continental Slope. Water depths greater than 1,000 meters represent the outer portion of the Continental Slope and the deep ocean basin area of the Gulf of Mexico.

Estimates made by the Area Work Committees include resources beneath areas presently withdrawn or proposed for withdrawal from exploration and development because of governmental action. Where considerable potential exists beneath these withdrawn areas, it is appropriate that estimates of this potential be made and presented in the narrative submitted by each Area Committee.

Economic, technological and policy considerations

Economic, technological and governmental policy considerations taken into account in the Potential Gas Committee's estimate of potential gas supply are related to (1) past production and proved reserves of natural gas, and (2) all wells that would be drilled in the future under the assumed conditions of adequate economic incentives in terms of price/cost relationships and current or foreseeable technology. Fundamental economic considerations—which include but are not limited to prices, costs, rates of take, recovery factors, abandonment pressures, etc.—are inherent in the definition of proved reserves:

"... recoverable in the future from known oil and gas reservoirs under existing economic and operating conditions."

Some gas that is actually present in known reservoirs is not producible because of unfavorable present or foreseeable price/cost relationships and, therefore, is not included in recoverable reserves. Furthermore, there are other known gas accumulations of such small size that none of the gas can be produced in commercial quantities under "... existing economic and operating conditions." Such considerations result in proved reserves being somewhat less than the total volumes of gas existing in known reservoirs. These same limitations are applicable to the estimates of potential resources. If a fundamental change in economics or technology occurs, estimates of potential resources will be changed accordingly.

The attribution technique presented in Estimation of Potential Gas Supply describes relationships between ultimately recoverable volumes of gas from known occurrences and prospective gas accumulations, after appropriate adjustment for variations in geological and reservoir conditions. The explicit assumptions of adequate but reasonable prices and normal improvements in technology in the definition of potential resources relate to improvements in exploration and production techniques. Adequate prices, normal technological improvements and reasonable governmental policies are required to bring about the drilling necessary to prove the potential resources. These assumed conditions permit estimates of potential resources to be made by the Potential Gas Committee on the basis of relevant past history and experience concerning recovery factors, as well as the size and type of reservoirs that have been found, developed, and produced, without speculating as to future levels of prices and costs.

Statistical aggregation of gas resource estimates

The estimates reported for each of the individual Potential Gas Committee provinces provide valid and useful data for the natural gas industry. **The estimates for the individual provinces, Tables 9-16, are of the greatest value for purposes of planning and exploration, and represent the best judgment of the individual Committee members.**

The Potential Gas Committee has traditionally also reported the gas resource estimates for the seven Work Areas and the National totals by summing the numbers arithmetically. The values used for these summations were the "most likely" values, the value of the statistical mode. This is the estimate with the highest probability of occurrence. Although this approach has given a reasonable picture of the total of the estimates for purposes of comparison with previous PGC work and

the results of other resource estimators, it has not taken into account the fact that the data provided by the PGC members, the minimum, most likely, and maximum estimates, are not pure numbers, but rather comprise a statistical distribution. The values that make up this distribution each have a varying probability of occurrence. Additionally, the distributions are most often not mathematically dependent and therefore may not be rigorously summed arithmetically.

The lack of statistical rigor in summing and reporting the Area and National totals was recognized by members of the Potential Gas Committee in the past, but the Committee did not possess the capability to aggregate the data using, for example, Monte Carlo sampling techniques. With the recent availability of Monte Carlo-type programs designed to run on personal computers, the more rigorous handling of the estimates is now possible, and has been completed for this report.

Details of the particular approach taken by the PGC for the 1990 aggregation of Area and National resource estimates may be found in the Appendix.

The 1990 Area totals (Table 7) were calculated by statistical aggregation of the minimum, most likely and maximum values for the provinces in each Area. The National total was then derived by statistical aggregation of the province data.

Because of the state of knowledge of the coalbed methane resource, these estimates were calculated separately and the means of the aggregation added to the totals shown in Table 7, instead of being aggregated with the traditional resource estimates.

In order to compare the statistically aggregated 1990 estimates with the year-end 1988 Potential Gas Committee resource estimates, the same statistical aggregation has been applied to the 1988 data (including, for comparative purposes, the additional 24,600 Bcf for Alaska Probable estimates, previously carried as Proved Reserves). A comparison of the 1988 and 1990 data (Table 8) indicates that the 1990 aggregated estimates are approximately two percent higher than the 1988 aggregated estimates, approximately the same increase seen in a comparison of the most likely values.

Comparison of the arithmetic sum of the most likely values and the statistically aggregated means can be made by reference to Tables 2 and 7. The sum of the means of the traditional resources give a result that is approximately 19 percent higher than the sum of the most likely values. The relative directions of these changes are in accordance with statistical theory for aggregation of asymmetric probability distributions. **The Potential Gas Committee again emphasizes that the individual Province estimates provide the most useful data to the natural gas industry.** The increase of approximately 19 percent of the statistically aggregated estimates from the arithmetically summed most likely values is statistically valid.

National Summary Statistics

The following tables summarize the Potential Gas Committee resource estimates on a national basis. Additionally, data have been derived from the Committee on Natural Gas Reserves of the American Gas Association,[3] and the Energy Information Administration.[4]

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[3] American Gas Association, 1980, Report of the Committee on Natural Gas Reserves, *in* Reserves of crude oil, natural gas liquids, and natural gas in the United States and Canada as of December 31, 1979: American Petroleum Institute, American Gas Association, and Canadian Petroleum Association, 253 p. (also annual reports for preceding years), Washington, DC.

[4] Energy Information Administration, 1989, U.S. crude oil, natural gas, and natural gas liquids reserves, 1989 annual report: U.S. Department of Energy, Energy Information Administration [DOE/EIA-0216(88)] (and reports for earlier years), Washington, DC.

Table 2. Potential Gas Committee 1990 estimates by Area
(Most Likely Values—billion cubic feet)

AREA			PROBABLE	POSSIBLE	SPECULATIVE	TOTAL
Atlantic						
	Onshore	0-15000'	20,923	7,800	18,600	47,323
		15-30000'	**	400	12,350	12,750
		TOTAL	20,923	8,200	30,950	60,073
	Offshore	0-200m	**	**	14,800	14,800
		200-1000m	**	**	650	650
		TOTAL	**	**	15,450	15,450
	AREA TOTAL		20,923	8,200	46,400	75,523
North Central						
	Onshore	0-15000'	164	5,229	10,174	15,567
		15-30000'	**	**	*	*
	AREA TOTAL		164	5,229	10,174	15,567
Gulf Coast						
	Onshore	0-15000'	13,050	19,190	10,710	42,950
		15-30000'	10,400	18,750	11,310	40,460
		TOTAL	23,450	37,940	22,020	83,410
	Offshore	0-200m	21,500	33,050	7,600	62,150
		200-1000m	1,490	18,600	6,550	26,640
		>1000m	**	**	30,000	30,000
		TOTAL	22,990	51,650	44,150	118,790
	AREA TOTAL		46,440	89,590	66,170	202,200
Mid-Continent						
	Onshore	0-15000'	27,843	37,994	23,488	89,325
		15-30000'	16,100	23,178	4,600	43,878
	AREA TOTAL		43,943	61,172	28,088	133,203
Rocky Mountain						
	Onshore	0-15000'	30,224	37,145	12,525	79,894
		15-30000'	13,250	22,148	5,400	40,798
	AREA TOTAL		43,474	59,293	17,925	120,692
Pacific						
	Onshore	0-15000'	1,200	4,600	7,000	12,800
		15-30000'	200	750	500	1,450
		TOTAL	1,400	5,350	7,500	14,250
	Offshore	0-200m	55	5,200	1,800	7,055
		200-1000m	65	4,700	4,100	8,865
		TOTAL	120	9,900	5,900	15,920
	AREA TOTAL		1,520	15,250	13,400	30,170
TOTAL LOWER 48 STATES			156,464	238,734	182,157	577,355
Alaska						
	Onshore	0-15000'	31,250	16,400	27,700	75,350
		15-30000'	**	**	*	*
		TOTAL	31,250	16,400	27,700	75,350
	Offshore	0-200m	2,400	12,700	50,350	65,450
		200-1000m	**	**	2,650	2,650
		TOTAL	2,400	12,700	53,000	68,100
	AREA TOTAL		33,650	29,100	80,700	143,450
TOTAL UNITED STATES			190,114	267,834	262,857	720,805
COAL BED METHANE			9,576	51,208	84,358	145,142
GRAND TOTAL UNITED STATES			199,690	319,042	347,215	865,947

* Negligible quantity of natural gas estimated
** Production has not been established; no Probable or Possible resource exists

Table 3. Potential Gas Committee 1990 estimates — total United States
(Most Likely Values — billion cubic feet)

	PROBABLE	POSSIBLE	SPECULATIVE	TOTAL
ONSHORE (drilling depth)				
Lower 48 States				
less than 15000 feet	93,404	111,958	82,497	287,859
15000 to 30000 feet	39,950	65,226	34,160	139,336
Alaska				
less than 15000 feet	31,250	16,400	27,700	75,350
15000 to 30000 feet	**	**	*	**
TOTAL ONSHORE	164,604	193,584	144,357	502,545
OFFSHORE (water depth)				
Lower 48 States				
less than 200 meters	21,555	38,250	24,200	84,005
200 to 1000 meters	1,555	23,300	11,300	36,155
greater than 1000 meters	**	**	30,000	30,000
Alaska				
less than 200 meters	2,400	12,700	50,350	65,450
200 to 1000 meters	**	**	2,650	2,650
TOTAL OFFSHORE	25,510	74,250	118,500	218,260
TOTAL LOWER 48 STATES	156,464	238,734	182,157	577,355
TOTAL ALASKA	33,650	2[illegible]100	80,700	143,450
TOTAL UNITED STATES	190,114	267,834	262,857	720,805
COALBED METHANE	9,576	51,208	84,358	145,142
GRAND TOTAL UNITED STATES	199,690	319,042	347,215	865,947

*Negligible quantity of natural gas estimated
** Production has not been established; no Probable or Possible resource exists

Table 4. Comparison of estimates of ultimately recoverable volumes of natural gas in the United States (trillion cubic feet)

Total United States

Year	Cumulative Production (1)	Proved Reserves (2)	Potential Resources (3)	Coalbed Methane (3)	Estimated Future Supply*	Ultimately Recoverable Resource**
1968	345	287	1227		1514	1859
1970	387	291	1178		1469	1856
1972	432	266	1146		1412	1844
1974	477	237	1146		1383	1860
1976	515	216	948		1164	1679
1978	553	200	1019		1219	1772
1980	596	199	913		1112	1708
1982	632	202	876		1078	1710
1984	665	196	784		980	1645
1986	697	193	739		932	1629
1988	730	187	706	90	983	1713
1990	765 est.	167 est.	721	145	1033	1798

Lower 48 states

Year	Cumulative Production (1)	Proved Reserves (2)	Potential Resources (3)	Coalbed Methane (3)	Estimated Future Supply*	Ultimately Recoverable Resource**
1966	300	286	690		976	1276
1968	345	282	795		1077	1422
1970	388	260	851		1111	1499
1972	432	235	780		1015	1447
1974	476	205	780		985	1461
1976	514	184	748		932	1446
1978	532	177	830		1007	1539
1980	571	163	768		931	1502
1982	613	169	742		911	1524
1984	662	163	647		810	1472
1986	693	160	620		780	1473
1988	726	159	587	90	836	1562
1990	760 est.	158 est.	577	88	823	1583

(1) Cumulative production figures derived from A.G.A. Committee on Natural Gas Reserves, plus annual production reports from US Department of Energy, Energy Information Administration. Cumulative production shown for 1988 is an estimate only.

(2) Proved reserves derived from reports of the A.G.A. Committee on Natural Gas Reserves for years through 1979. Proved reserves for years from 1980 on are derived from reports of US Department of Energy, Energy Information Administration. Proved reserves shown for 1988 are 1987 estimates.

(3) Potential resources and coalbed methane from estimates of Potential Gas Committee (most likely values).

*Proved reserves + potential resources + coalbed methane.

**Future supply + cumulative production.

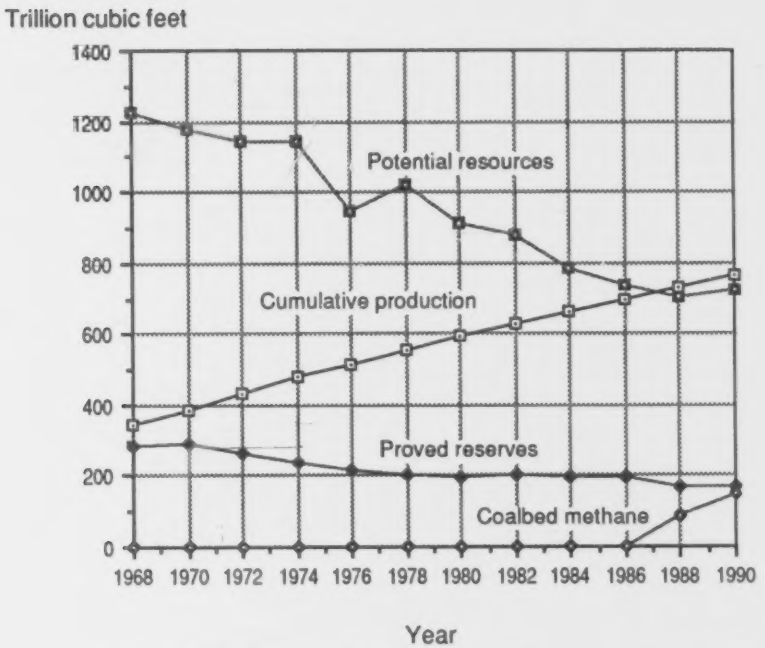

Figure 5. Biennial estimates of cumulative production, proved reserves and potential resources of natural gas in the total United States.

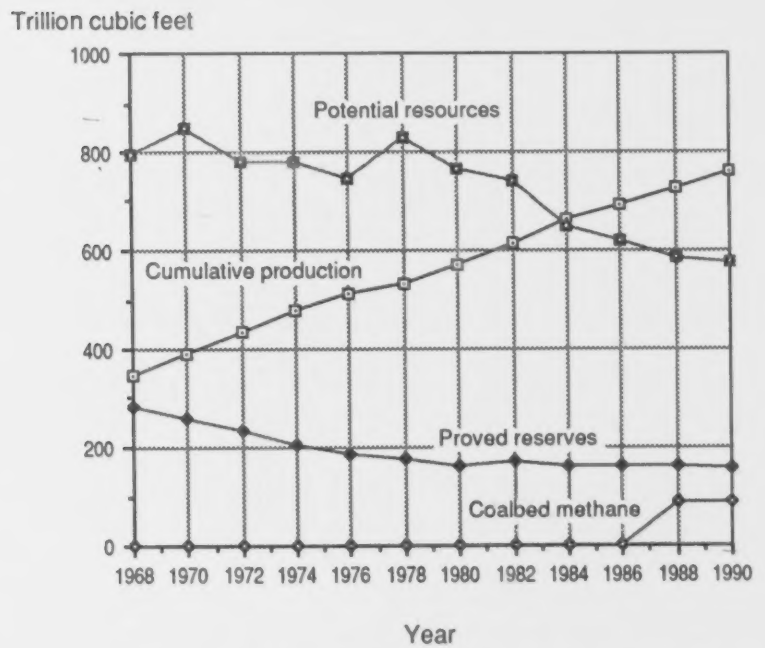

Figure 6. Biennial estimates of cumulative production, proved reserves and potential resources of natural gas in the Lower 48 states.

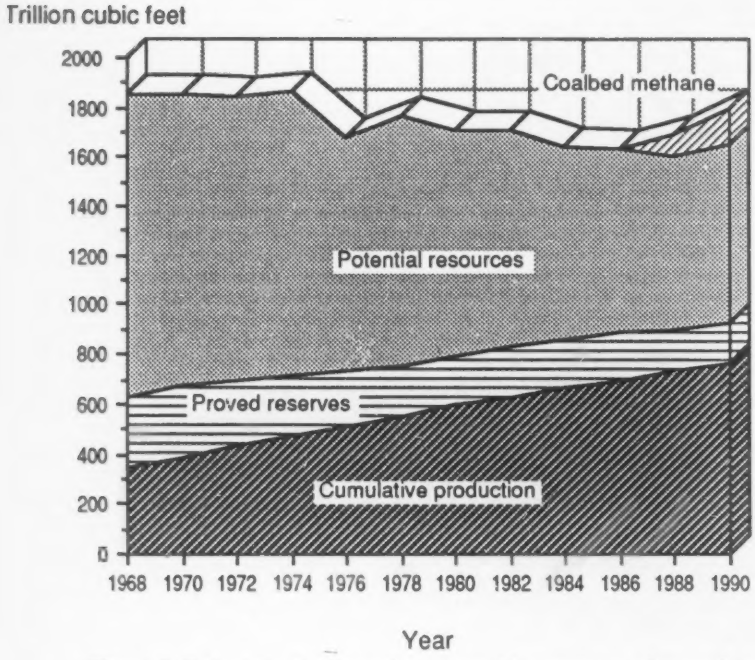

Figure 7. Estimates of ultimately recoverable resources of natural gas in the total United States.

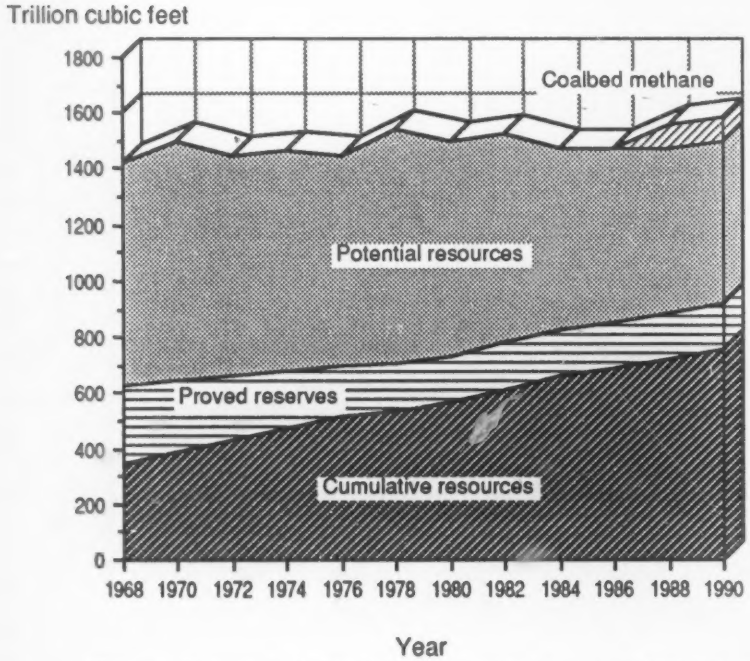

Figure 8. Estimates of ultimately recoverable resources of natural gas in the Lower 48 states.

Table 5. Comparison of estimates of potential resources of natural gas from Potential Gas Committee reports
(Most Likely Values — trillion cubic feet)

	PROBABLE RESOURCES	POSSIBLE RESOURCES	SPECULATIVE RESOURCES	TOTAL RESOURCES
TOTAL UNITED STATES				
As of 12-31-68	260	335	632	1,227
As of 12-31-70	257	387	534	1,178
As of 12-31-72	266	384	496	1,146
As of 12-31-76	215	363	345 to 395	923 to 973
As of 12-31-78	199	399	421	1,019
As of 12-31-80	193	358	362	913
As of 12-31-82	192	355	329	876
As of 12-31-84	185	293	306	784
As of 12-31-86	163	298	278	739
As of 12-31-88	173	267	265	706
As of 12-31-90	190	268	263	721
LOWER 48 STATES				
As of 12-31-66	300	210	180	690
As of 12-31-68	238	317	240	795
As of 12-31-70	218	326	307	851
As of 12-31-72	212	290	278	780
As of 12-31-76	192	318	188 to 238	698 to 748
As of 12-31-78	186	359	285	830
As of 12-31-80	185	329	254	768
As of 12-31-82	184	326	232	742
As of 12-31-84	176	264	207	647
As of 12-31-86	154	269	197	620
As of 12-31-88	164	238	185	587
As of 12-31-90	156	239	182	577

(Note: Estimates exclude coalbed methane resources)

Table 6. Comparison of estimates, 1988 and 1990, by Area
(Most Likely Values — billion cubic feet)

AREA		PROBABLE		POSSIBLE		SPECULATIVE	
		1988	1990	1988	1990	1988	1990
ATLANTIC							
	Onshore	22,000	20,923	8,200	8,200	30,950	30,950
	Offshore	**	**	**	**	15,450	15,450
	TOTAL	22,000	20,923	8,200	8,200	46,400	46,400
NORTH CENTRAL							
	TOTAL	1,750	164	6,850	5,229	10,300	10,174
GULF COAST							
	Onshore	22,750	23,450	35,900	37,940	16,000	22,020
	Offshore	26,500	22,990	55,200	51,650	47,200	44,150
	TOTAL	49,250	46,440	91,100	89,590	63,200	66,170
MID-CONTINENT							
	TOTAL	45,800	43,943	61,650	61,172	31,600	28,088
ROCKY MOUNTAIN							
	TOTAL	44,000	43,474	55,000	59,293	20,750	17,925
PACIFIC							
	Onshore	1,550	1,400	6,200	5,350	6,500	7,500
	Offshore	100	120	8,950	9,900	5,800	5,900
	TOTAL	1,650	1,520	15,150	15,250	12,300	13,400
TOTAL LOWER 48 STATES		164,450	156,464	237,950	238,734	184,550	182,157
ALASKA							
	Onshore	6,350	31,250 ***	16,400	16,400	27,700	27,700
	Offshore	2,400	2,400	12,700	12,700	53,000	53,000
	TOTAL	8,750	33,650	29,100	29,100	80,700	80,700
TOTAL UNITED STATES		173,200	190,114	267,050	267,834	265,250	262,857

**Production has not been established; no Probable or Possible resource exists.
***Includes additional 24,600 Bcf Probable Resources for P-701, North Slope province.

Table 7. Potential Gas Committee 1990 estimates by Area
(Mean Values by Statistical Aggregation — billion cubic feet)

AREA	PROBABLE	POSSIBLE	SPECULATIVE	TOTAL
Atlantic				
Onshore	29,163	12,833	44,616	
Offshore	**	**	19,483	
AREA TOTAL	29,163	12,833	64,077	106,085
North Central				
Onshore	180	5,771	14,412	
AREA TOTAL	180	5,771	14,412	20,363
Gulf Coast				
Onshore	23,163	38,638	32,263	
Offshore	22,011	57,234	45,503	
AREA TOTAL	45,175	95,864	77,806	218,820
Mid-Continent				
Onshore	48,106	65,981	32,258	
AREA TOTAL	48,106	65,981	32,258	146,344
Rocky Mountain				
Onshore	45,218	65,413	22,455	
AREA TOTAL	45,218	65,413	22,455	133,086
Pacific				
Onshore	1,590	6,250	11,566	
Offshore	127	10,533	6,300	
AREA TOTAL	1,717	16,783	17,867	36,366
TOTAL LOWER 48 STATES	169,562	262,651	228,766	661,095
Alaska				
Onshore	32,150	22,300	40,417	
Offshore	5,134	19,499	74,788	
AREA TOTAL	37,288	41,816	115,129	194,296
TOTAL UNITED STATES	206,840	304,417	344,034	855,329
COAL BED METHANE	9,135	59,425	78,743	147,302
GRAND TOTAL UNITED STATES	215,975	363,842	422,777	1,002,631

* Negligible quantity of natural gas estimated
** Production has not been established; no Probable or Possible resource exists
Note: Totals subject to rounding and slight differences due to statistical aggregation of distributions
Coalbed estimates arithmetically added to derive Grand Total.

Table 8. Comparison of estimates, 1988 and 1990, by Area
(Mean Values by Statistical Aggregation — billion cubic feet)

AREA	PROBABLE MEAN		POSSIBLE MEAN		SPECULATIVE MEAN	
	1988	1990	1988	1990	1988	1990
ATLANTIC	30,202	29,163	12,833	12,833	64,082	64,077
NORTH CENTRAL	1,733	180	7,750	5,771	14,500	14,412
GULF COAST	47,350	45,175	92,649	95,864	62,268	77,806
MID-CONTINENT	50,900	48,106	64,216	65,981	35,267	32,258
ROCKY MOUNTAIN	45,783	45,218	60,033	65,413	23,917	22,455
PACIFIC	1,800	1,717	16,500	16,783	16,850	17,867
TOTAL LOWER 48 STATES	177,771	169,562	253,983	262,651	216,897	228,766
ALASKA **	37,184	37,288	41,784	41,816	115,165	115,129
TOTAL UNITED STATES (Statistically aggregated totals)	214,953	206,840	295,768	304,417	332,064	344,034

** The 1988 Probable figure includes 24,600 Bcf for comparative purposes
Note: Totals subject to rounding and slight differences due to statistical aggregation of distributions.

POTENTIAL GAS COMMITTEE

NATURAL GAS RESOURCE ESTIMATES

(December 31, 1990)

The following pages comprise the Potential Gas Committee's estimate of potential natural gas resources for the United States as of December 31, 1990. The estimates are presented by Work Area and by geologic province within each Work Area. A separate section on coalbed methane is also included.

A summary of the geology and natural gas resource potential for each geologic province is presented in order to provide the reader with brief background information about the province. This summary is not intended to be an exhaustive treatment, but rather to cover the fundamental geologic setting and its significance relative to natural gas occurrence. Information has been derived from a number of sources, especially Landes[1] and Cram.[2] Additional information has been provided in personal communication from members of the Potential Gas Committee.

Generalized stratigraphic sections have been provided for a number of the geologic provinces, especially those with significant natural gas potential. These stratigraphic sections are not necessarily accurate in all details, but they should serve to orient the reader concerning the stratigraphic position and age of reservoir and source rocks mentioned in the text. In addition to the sources listed for the geologic summaries, information for the stratigraphic sections has been derived from the published stratigraphic sections of the COSUNA project.[3]

Stratigraphic sections have been annotated to indicate those formations presently or potentially productive of natural gas. Formations that are currently productive of gas in commercial quantities, or have been productive of gas in the past, are indicated by an asterisk (*). Formations that, in the judgment of PGC members, have the potential to be productive of natural gas, but that are not currently productive within the province, are indicated by a dagger sign (†). Other formations are not considered potentially productive.

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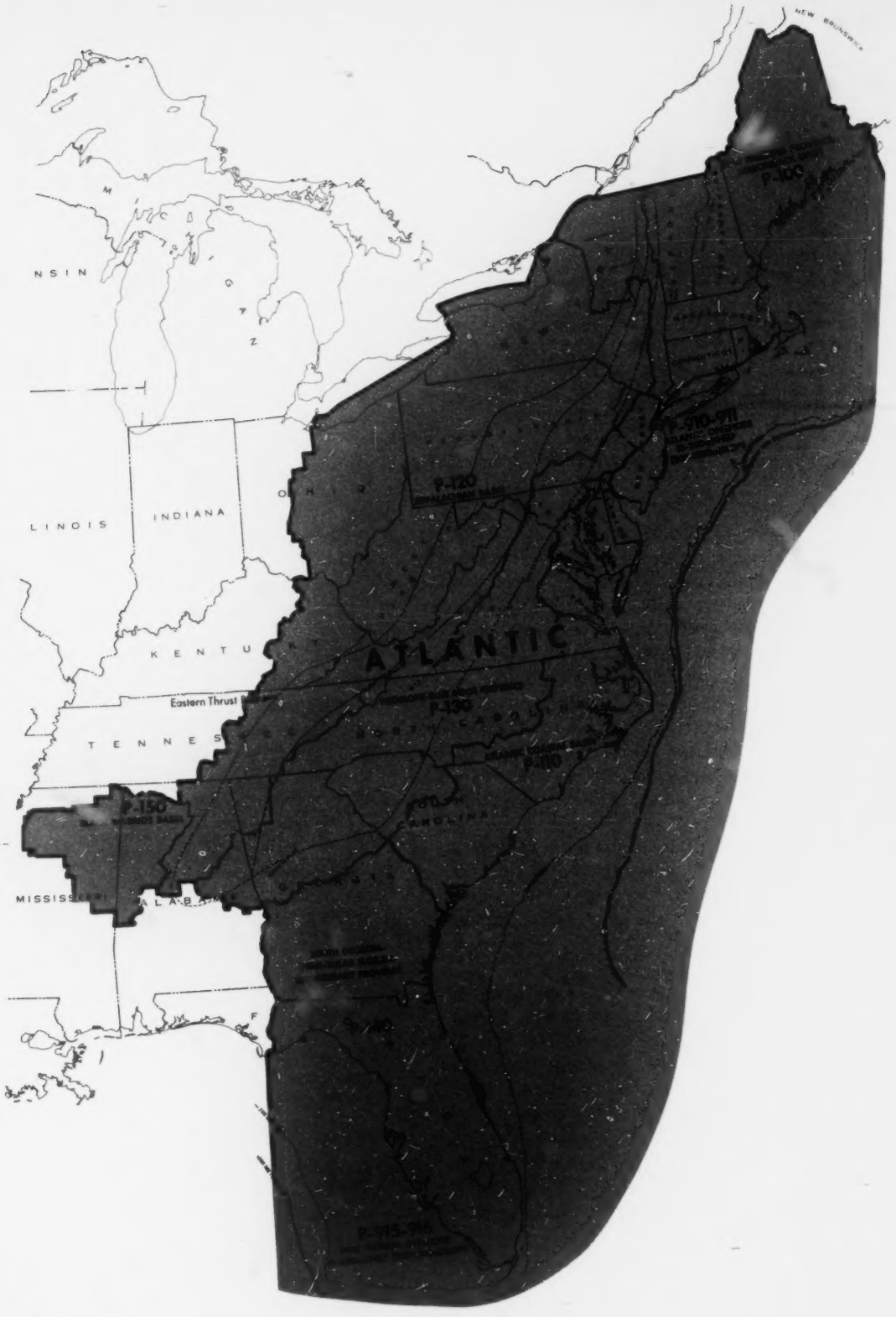
[1] Landes, K. K., 1970, Petroleum Geology of the United States: Wiley-Interscience, New York, 571 p.

[2] Cram, I. H., ed., 1971, Future Petroleum Provinces of the United States–Their Geology and Potential: American Association of Petroleum Geologists, Memoir 15, Tulsa, OK, 1,496 p.

[3] Correlation of Stratigraphic Units of North America (COSUNA) Project: American Association of Petroleum Geologists, Tulsa, OK.


NEW BRUNSWICK
P-100
NSIN
P-910-911
P-120
LINOIS
INDIANA
ATLANTIC
KENTU
Eastern Thrust
P-130
TENNES
P-150
MISSISS
ALA.
P-915-916

ATLANTIC AREA

The only geologic provinces of the Atlantic Area currently productive of natural gas are the Appalachian basin and the Black Warrior basin. Other provinces that have potential for future resource development are the New England province and Adirondack uplift, the Atlantic Coastal basin, the Piedmont-Blue Ridge province, the South Georgia-Peninsular Florida sedimentary province, and the Atlantic and West Florida Offshore provinces.

P-100, NEW ENGLAND PROVINCE AND ADIRONDACK UPLIFT

This province includes the states of Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, Vermont and 14 counties in eastern New York State. No production of oil or natural gas has been established in this area. Sedimentary rocks in the area are predominantly of Paleozoic age, reaching a thickness of 15,000 to 20,000 feet. Additionally, there is a thick sequence of sedimentary rocks of Triassic age in the Connecticut Triassic basin. All postulated natural gas potential is located in the Connecticut Triassic basin and in the Eastern Thrust Belt, which extends into eastern New York and western Vermont. Potential reservoir rocks in the Eastern Thrust Belt are of Ordovician and Cambrian age and occur both in the area of surface exposure of Paleozoic rocks (west) and the area in which the Paleozoic rocks are concealed beneath thrusted older rocks (east).

P-110, ATLANTIC COASTAL BASIN

This province includes the entire state of Delaware and portions of New Jersey, Maryland, Virginia, North Carolina and South Carolina. No production of oil or gas has been established to date. The province is bordered generally on the west by the Appalachian and Blue Ridge Mountains and includes an area of over 108,000 square miles. Sedimentary rocks range in age from Triassic(?) or Jurassic to Quaternary. Recent geophysical surveys and deep drilling have established that there are greater thicknesses of sedimentary rocks in this province than previously thought, greatly in excess of previous estimates of 10,000 feet. Potential for natural gas is believed to be limited largely to the Triassic basins, both those in which Triassic rocks are exposed at the surface and those in which younger sedimentary rocks cover the Triassic. There is also some potential in the deeper formations in the coastal areas of North and South Carolina.

P-110, ATLANTIC COASTAL BASIN
Generalized Stratigraphic Section

AGE	FORMATION		
	NORTH		SOUTH
Cenozoic			
Quaternary			Holocene-Pleistocene deposits
Tertiary			
Pliocene			Yorktown Fm.
Miocene	Kirkwood Fm.-St. Marys Fm.-Choptank Fm.-Calvert Fm.-Hawthorn Fm.		
		Pungo R. Fm.	
Oligocene		River Bend Fm.-Cooper Fm.	
Eocene	Deal Fm.	Nanjemoy Fm.-Pamunkey Gp.-Castle Hayne Fm.-Santee Ls.-Huber Fm.	
		Black Mingo Fm.	
Paleocene	Hornerstown Fm.		
Mesozoic			
Cretaceous			
Late	Monmouth Gp.-Mt. Laurel Sd.	unit "A"	Peedee Fm.
	Matawan Fm.	unit "B"	Black Creek Fm.
	Magothy Fm.	unit "C"	
	Raritan Fm.	unit "D"	Middendorf Fm.
		unit "E"	Cape Fear Fm.
		unit "F"	
† Early		unit "G"	
	Potomac Gp. (Fm.)	unit "H"	
† Jurassic(?)			
Triassic(?)	Newark Gp.	unnamed red beds	
Pre-Mesozoic basement			

† Potentially productive

P-120, APPALACHIAN BASIN

The Appalachian basin province covers an area of over 180,000 square miles in portions of the states of New York, Pennsylvania, New Jersey, West Virginia, Virginia, Maryland, Ohio, Kentucky, Tennessee, Georgia and Alabama. Its eastern border includes the Appalachian Mountains, and it extends westward to the Cincinnati arch and the Nashville dome. Sedimentary rocks in the basin exceed thicknesses of 30,000 feet in places, and potential reservoir rocks range in age from Cambrian to Pennsylvanian.

Although several hundred thousand wells have been drilled in the Appalachian basin, most of them have been relatively shallow (less than 5,000 feet) and concentrated along narrow producing trends. In the entire basin, only eleven wells have been drilled to a depth deeper than 15,000 feet. Only 10-15 percent of the possible hydrocarbon-producing sedimentary rocks have been tested and, in terms of exploration, the basin is relatively young.

Probable resources are expected to be found mostly in field extensions, infill drilling and connecting old fields. Possible resources are expected to be found in fields ranging in size from 5 to 500 Bcf with most of them being in the 15 to 50 Bcf range. Speculative resources are expected to be found in fields ranging in size from 50 to 1,000 Bcf with the most likely size being between 300 and 500 Bcf.

Reservoir rocks. Both detrital rocks and carbonates form potential reservoirs, and production has already been established from most potential reservoirs in at least some part of the basin. Production from Mississippian-Pennsylvanian, Devonian, Silurian, middle Upper Ordovician and Cambro-Ordovician units is located, generally, along long, regional anticlinal trends that are oriented in a northeast-southwest direction. Fracturing plays an important role in the deeper reservoirs.

Traps. Stratigraphic, structural and combination traps are all abundant. Lenses, reefs and porosity variations are most important in Silurian and Mississippian reservoirs. Truncations are characteristic of Silurian-Ordovician strata. Production from widespread Devonian shales is closely related to regional fracturing patterns. Shales also form traps and seals for contained sandstone lenses. Anticlines and faulted anticlines form major traps for hydrocarbons in Devonian and Carboniferous reservoirs.

Potential source rocks. Probable source rocks for both oil and gas range from the thermally moderately mature to severely altered Middle Cambrian Rome Shale Formation gas generators to the Middle to Upper Mississippian Big Lime Formation, which is a thermally moderately mature to immature source for both oil and gas. Surface seeps, tar sands and solid hydrocarbon exposures are all known from the province.

Producing trends. The central portion of the basin is basically one giant gas field, extending more than 500 miles along a northeast-southwest trend and 50 to 75 miles wide. A similar trend farther to the west parallels the giant field; here, gas production is generally more scattered throughout thousands of fields. This western trend defines the limit of the Appalachian basin in the west. The vast majority of the counties included within the limits of the Appalachian basin have at least some gas production. The Cambro-Ordovician Rome Formation is productive of both gas and oil at depths of almost 15,000 feet, whereas the Mississippian Berea sandstones and siltstones produce from the surface to depths of 6,100 feet.

Coalbed methane. The Appalachian basin is generally divided into three coal-bearing regions. The Anthracite Region of Pennsylvania, the Northern Appalachian basin, and the Central Appalachian basin.

The Anthracite Region of Pennsylvania extends over an area of approximately 500 square miles in the eastern portion of the state and includes four highly deformed, northeast-southwest-trending structural basins. The coal seams of the Anthracite Region are thought to be equivalent or nearly equivalent in age to the bituminous coal seams of the Appalachian basin. Locally, the anthracite seams can be quite thick, up to 65 feet, with principal coal seams (Mammoth, Red Ash, Peach Mountain, Seven Foot Leader) averaging 10 to 15 feet in thickness. Publicly available data is limited in this region and there has been little work in the Anthracite Region to determine the feasibility of producing natural gas from the coal seams.

Gas-content measurements recorded from several coal seams in the Anthracite Region are some of the highest in the United States however, the values are quite variable. The intense structural deformation of the basins probably plays an important role in the present distribution of gas in the coal. Only one well has been drilled in this region for the purpose of exploiting coalbed methane. The well was drilled near Nanticoke in Luzerne County on the flank of a small anticline. Successful coalbed methane development in anthracite probably will depend on locating wells in highly fractured areas.

The State of Pennsylvania estimates that there are 16 billion tons of anthracite reserves. Assuming 25 percent of the anthracite reserves are located under undrillable areas such as urban centers, lakes, etc., a resulting anthracite resource of 12 billion tons is obtained. Estimates place the speculative in-place coalbed methane resource for the Pennsylvania Anthracite Region between 380 and 4,300 Bcf. The most likely estimate of the recoverable resource at this time is 570 Bcf.

The Northern Appalachian basin, a northeast-southwest-trending basin covering an area of 30,300 square miles, encompasses portions of Pennsylvania, West Virginia, Ohio, Kentucky, and Maryland. The basin is bounded structurally on the southeastern and southern margins by the Rome trough. The outcrop of Pennsylvanian-age sediments defines the northeastern, northern and western boundaries of the basin. Coal seams of the basin are found in five groups, which in ascending order are the Pottsville, Allegheny, Conemaugh, Monongahela and Dunkard. Of these five groups, the Allegheny and Monongahela contain the bulk of the coal resources. Within the Allegheny Group major coal seams include the Brookville, the Kittanning and the Freeport seams. The Pittsburgh, Sewickley and Waynesburg seams are the principal seams of the Monongahela Group. Coal rank throughout most of the basin is predominantly high-volatile A bituminous. Along the eastern margin of the basin there is a strip of low- and medium-volatile bituminous coal.

Gas content values in the high-volatile A coal seams range from 41 to 441 scf/ton over the 1,000- to 2,000-foot depth range. In the low- and medium-volatile coal seams values of 300 to 400 scf/ton have been measured over the same depth range. Despite the fact that a great deal of the early coalbed methane research performed by the U.S. Bureau of Mines and the Department of Energy was conducted in the Northern Appalachian basin, currently there is no commercial production in the basin. Coal degasification wells associated with mining operations have existed in the province for many years, but commercial recovery of gas from these wells has been limited. The Big Run gas field in Wetzel County, West Virginia, has produced methane continuously since 1932 from an interval that includes the Pittsburgh coalbed. The field has produced an estimated 2.3 Bcf of gas. Estimates place the possible in-place coalbed methane resource for the Northern Appalachian basin between 4.1 and 44.1 Tcf. The most likely estimate of the recoverable resource at this time is 10 Tcf.

The Central Appalachian basin is a narrow, northwest-southeast-trending basin covering nearly 23,000 square miles over portions of Tennessee, Kentucky, Virginia and West Virginia. The eastern margin of the basin is defined by the areal extent of the Pennsylvanian-age Pocahontas Formation, which crops out in the northeast and is truncated by faulting in the southeast. The western edge of the basin approximates the trace of the Rome trough in the northwest and is delineated by the Irvine-Paint Creek Fault system in the southwest. Three major coal-bearing formations in the basin are the Pocahontas, New River/Lee and the Kanawha/Norton. More than 80 coal seams are present within these formations, which contain an estimated total coal tonnage of 80 to 120 billion tons. However, not all of these seams can be considered potential targets for coalbed methane development. Based on measured gas contents of the coal seams in the Central Appalachian basin, only those greater than 500 feet below drainage elevation have retained sufficient quantities of stored gas for possible

P-120, APPALACHIAN BASIN
Generalized Stratigraphic Section

AGE	NORTH	FORMATION	SOUTH	
Paleozoic				
Permian			* Dunkard Fm.	
Pennsylvanian			* Monongahela Fm.	
		Llewellyn Fm.	* Conemaugh Fm.	
			* Allegheny Fm.	
			* Pottsville Ss.	Kanawha Fm.
Mississippian		* Mauch Chunk Fm.		Parkwood-Pennington Fm.
		* Greenbrier Ls.		Floyd Shale-Bangor Ls.
		* Pocono Gp.		* Fort Payne Chert
Devonian	* Catskill Fm.- Chemung Fm.		* Ohio Sh.	† Chattanooga Sh.
	* Hamilton Gp.	Millboro Sh.		
		* Onondaga Ls.	* Huntersville Chert	
	* Oriskany Ss.			Frog Mountain Ss.
			* Helderberg Gp.	
Silurian		* Bass Islands Gp.		
	Salina Gp.		Tonoloway Fm.	
	* Lockport Fm.		McKenzie Fm.	
				* Keefer Ss.
				Rose Hill Fm.
	* Medina-Albion- Tuscarora Fm.		* Clinton Fm.	Clinch-Brassfield Fm.
Ordovician	* Queenston Fm.- Juniata Fm.			Sequatchie Fm.
	Utica Shale	Reedsville- Martinsburg Fm.		
	* Trenton- Black River Gps.		High Bridge- Chickamauga- Stones R. Gp.	
Cambro-Ord.	* Beekmantown Gp.			* Knox Gp.
Cambrian			* Copper Ridge Fm.	
	† Potsdam Ss.			Elbrook-Conasauga Gp.
				Nolichucky Sh.
			† Rome Fm.	
				Shady Dolo.
		basal formations		
Precambrian				

* Currently producing
† Potentially productive

commercial production. Due to the rugged topography in the region, there can be a considerable amount of relief (up to 2,000 feet) between drainage elevation and ridge crests. Topographic considerations limit the area available for coalbed methane development to approximately 5,000 square miles in the east-central portion of the basin. Major seams targeted for development in this area include the Pocahontas Nos. 3 and 4, Fire Creek/Lower Horsepen, Beckley/War Creek, Sewell/Lower Seaboard and the Iaeger/Jawbone.

The majority of the coal reserves in the potential development area are low-volatile bituminous in rank. Gas content values are correspondingly high, with values of 250 to 600 cf/ton recorded at depths between 1,500 to 2,500 feet. Over the last several years, operators have begun to initiate development projects within the Virginia portion of the basin. Over 50 wells have been drilled in Dickenson and Russell Counties, although a number of the wells are shut in due to problems with water disposal. Estimates place the possible in-place coalbed methane resource for the Central Appalachian basin between 3.5 and 8.4 Tcf. The most likely estimate of the recoverable resource at this time is 2.5 Tcf.

Reservoir rocks. Potential reservoir rocks are of Cambrian through Mississippian age. They are concealed by metamorphic rocks and granites that have been thrust westward over the younger sedimentary rocks. Suspected important reservoir formations include the Cambro-Ordovician Knox Dolomite, the Lower Cambrian Rome Formation (shale, sandstone and dolomite) and the Precambrian to Cambrian Chilhowee Group (fractured shale).

Traps. Major anticlines within the concealed sedimentary section are interpreted from seismic cross sections and are anticipated to be the principal trapping mechanism.

Potential source rocks. The Middle Ordovician and Cambrian shales are postulated to be potential source rocks for natural gas and are thermally mature. Gas shows have been reported from similar rocks to the west.

P-130, PIEDMONT—BLUE RIDGE PROVINCE

This province covers portions of the states of Alabama, Georgia, South Carolina, North Carolina, Tennessee, Virginia, Maryland, Delaware, Pennsylvania and New Jersey, and includes an area of approximately 94,000 square miles. The province lies within the Appalachian and Blue Ridge Mountain regions, and the Eastern, or Blue Ridge, Overthrust Belt is the major tectonic feature. Sedimentary rocks within the province are in excess of 30,000 feet thick and range in age from Precambrian upward but are mainly of early Paleozoic age. No oil or natural gas production has been established in this province to date.

P-140, SOUTH GEORGIA—PENINSULAR FLORIDA SEDIMENTARY PROVINCE

This province covers the southern half of Georgia and most of Florida with the exception of the Florida panhandle. It is bordered on the north by the Appalachian Mountain System. The major tectonic elements include the Southeast Georgia Embayment, the northeastern Appalachicola basin, and the South Florida basin. Sedimentary rocks reach a maximum thickness of 15,000 feet. Production of oil and associated/dissolved natural gas has been established in southern Florida, but the major natural gas production in Florida is located outside this province in the Florida panhandle (Province P-300).

P-140, S. GEORGIA–PENINSULAR FLORIDA,
P-915 AND P-916, W. FLORIDA OFFSHORE, SHELF AND SLOPE
Generalized Stratigraphic Section

AGE	FORMATION	
	NORTH	SOUTH
Cenozoic		
Miocene	Hawthorne Gp.	Hawthorne Gp.
Oligocene	unnamed limestone	Suwanee Fm.
Eocene	unnamed limestone	Ocala Fm.
	unnamed limestone	Avon Park Fm.
	unnamed limestone	Oldsmar Fm.
Paleocene	† Cedar Keys Fm.	† Cedar Keys Fm.
Mesozoic		
Cretaceous		
Late	unnamed sand & Pine Key Fm.	Pine Key Fm.
	Atkinson Fm.	Atkinson Fm.
Early	unnamed sandstone & shale	Marquesas Supergroup
		Big Cypress Gp.
		† Dollar Bay Fm.
		Gordon Pass Fm.
		Marco Junction Fm.
		Ocean Reef Gp.
		Rattlesnake Hammock Fm.
		Lake Trafford Fm.
		* Sunniland Ls.
		Glades Gp.
		Punta Gorda Anhydrite
		Abel Mbr.
		Twelve Mile Mbr.
		West Felda Sh.
		† Lehigh Acres Fm.
		Pumpkin Bay Fm.
		Bone Island Fm.
		Wood River Fm.
		unnamed volcanic complex
		unnamed volcanic complex

* Currently producing
† Potentially productive

Reservoir rocks. Sedimentary rocks in the province range in age from Early Cretaceous to Tertiary and include limestone, dolomite and sandstone. Reservoir rocks for oil and associated/dissolved gas are principally Lower Cretaceous limestones at depths of up to 9,000 feet.

Traps. Changes in porosity and permeability within the carbonate reservoir rocks, possibly associated with folds, are the principal trapping mechanisms.

Potential source rocks. Potential source rocks for gas and oil include the thermally immature Cedar Keys Formation (Paleocene) and the moderately mature Sunniland Limestone (Lower Cretaceous).

P-150, BLACK WARRIOR BASIN

The Black Warrior basin is a triangular-shaped area located in northeastern Mississippi and northwestern Alabama. The basin extends over approximately 21,000 square miles. The Black Warrior basin is bounded on the north by the Nashville and Ozark domes, on the southeast by the Appalachian tectonic belt and on the southwest by the central Mississippi deformed belt. The sedimentary section is thicker than 20,000 feet in the deeper portion of the basin. The Black Warrior basin is currently a major producing area for natural gas, most of which is found above depths of 6,000 feet, with only minor accumulations of oil. Recovery of natural gas associated with coal seams is becoming increasingly important.

In terms of exploration maturity, the Black Warrior basin can be divided into three areas: 1) the shallow northern and eastern portions of the basin, an area that is sparsely drilled and is considered to be immature but having the potential for discovery of a number of fields of relatively small size because of both stratigraphy and depth; 2) the central portion of the basin, which is considered to be in early maturity and which holds the potential for several small- and moderate-size new field discoveries and a large number of field extensions; and 3) the southern, deeper portion of the basin, which holds the potential for some intermediate- and large-size field discoveries. Sedimentary rocks in this area exceed 20,000 feet in thickness. Only seven wells have been drilled to a depth greater than 12,000 feet in the entire Black Warrior basin, and only four wells have been drilled below 15,000 feet. The interaction of structure, stratigraphy and diagenesis in the deeper portion of the Black Warrior basin is relatively unknown and will control the size and number of fields discovered.

Reservoir rocks. Production in the Black Warrior basin is primarily from Paleozoic clastics of the Mississippian Chester Series. The sandstones of the Pennsylvanian Pottsville Formation also produce some hydrocarbons. Potential reservoir rocks range from Precambrian to Pennsylvanian age and consist of sandstone, limestone, dolomite and chert.

Traps. Hydrocarbon traps in the Black Warrior basin are primarily combination traps involving anticlines, faulted anticlines, high-angle normal faults and stratigraphy. Channel and bar sandstones provide stratigraphic traps in the Chester Series and Pottsville Formation. Stratigraphic traps usually have a structural component. Porosity variations in the carbonate sequences provide potential traps for hydrocarbons alone or in combination with structure and faulting.

Potential source rocks. The Mississippian Chester Series is thermally mature to very mature and provides sources for both gas and oil. The thermally mature Pennsylvanian Pottsville Formation and the mature to very mature Ordovician Black River Group would probably be sources primarily for gas.

Coalbed methane. The Lower Pennsylvanian Pottsville Formation is the coal-bearing unit in the basin, containing upwards of 40 net feet of high-rank coal in the area of present drilling activity, at depths from surface to more than 3,500 feet. The major, or target, coal groups in the basin, in descending order, are the Cobb, Pratt, Mary Lee, Black Creek and the "J" interval. The east-central part of the basin contains the highest rank coal, low- to medium-volatile bituminous, with in situ gas contents ranging from approximately 50 scf/ton to 540 scf/ton at 1,050 feet.

To date, most coalbed methane development has taken place in the eastern portion of the basin. The total number of coalbed methane wells drilled as of 9/1/90 is 1,414, with cumulative production in excess of 122 Bcf gas. The active degasification fields in the Black War-

P-150, BLACK WARRIOR BASIN
Generalized Stratigraphic Section

AGE	FORMATION	
	NE MISSISSIPPI	NW ALABAMA
Cenozoic		
Paleocene	Porters Creek Clay	
Mesozoic	Clayton Fm.	
Cretaceous		
Late	Prairie Bluff Chalk	
	Owl Creek Fm.	
	Ripley Fm.	
	Demopolis Chalk	
	Mooreville Chalk-Coffee Sand	
	Eutaw Fm.	
	Tuscaloosa Gp.	
Early	unnamed sandstone and conglomerate	
Paleozoic		
Pennsylvanian		
	* Pottsville Fm.	* Pottsville Fm.
Mississippian		
	Chester Series	
	† Parkwood Fm.	Bangor Ls.
	Floyd Sh.	Hartselle Ss.
		Pride Mountain Sh.
		Monteagle Ls.
	† Tuscumbia Ls.	† Tuscumbia Ls.
	† Fort Payne Chert	
Devonian	"Devonian Chert" (Arkansas Novaculite)	† Chattanooga Sh.
Silurian	unnamed cherty carbonate rocks	Silurian undiff.
Ordovician	Sequatchie Fm.	Sequatchie Fm.
		Maysville Gp.
		Nashville Gp.
	Chickamauga Gp.	Stones River Gp.
Cambro-Ordovician	† Knox Gp.	† Knox Gp.
Cambrian	unnamed pre-Knox carbonates	Ketona Dolo.
	unnamed sandstone	Conasauga Fm.
		Rome Fm.

* Currently producing
† Potentially productive

rior basin include the Big Sandy Creek, Blue Creek, Boone Creek, Brookwood, Cedar Cove, Deerlick Creek, Gurnee, Holt, Little Sandy Creek, Moundville, Oak Grove, Peterson, Pleasant Grove, Robinson's Bend, White Oak Creek and Wolf Creek fields. Total daily production in 1991 is expected to be more than 225 MMcf/day; in 1992, more than 300 MMcf/day. Operators have started to explore the deeper western portion of the basin. The Mississippi Bureau of Geology has recently released a geologic assessment of coalbed methane resources in Clay County, Mississippi.

It is estimated that the main coal groups in the basin contain 19.8 Tcf gas in-place; nearly 40 percent of this is in the Black Creek Group, the deepest of the five. The estimated most likely recoverable resource is 7.0 Tcf.

Note: According to the State Oil and Gas Board of Alabama, as of 12/31/90, the total number of producing wells in the Black Warrior basin was 1770, with cumulative production of nearly 130 Bcf. However, 9/1/90 figures were used to calculate estimates appearing in this report, not the 12/31/90 figures.

P-910 AND P-911, ATLANTIC OFFSHORE, SHELF AND SLOPE

These provinces cover the entire Atlantic offshore area of the United States. Major tectonic features include the Yarmouth arch, Georges Bank basin, Baltimore Canyon Trough, Southeast Georgia Embayment, the Carolina Trough and Platform, Blake Plateau basin, South Florida-Bahamas basin, and the Peninsular arch of Florida. No natural gas or oil production has been established in the province, although the existence of moderate quantities of gas has been established in at least one area. The accumulation of gas discovered was not sufficient to warrant installation of production facilities. Even though results to date have not been encouraging, numerous concepts and plays remain unevaluated and present some possibility for the existence of natural gas resources. Considering the size of the Atlantic offshore area and the sparsity and uneven distribution of wells, the province must still be considered immature from the standpoint of exploration. If production is established, the fields would have to be intermediate to large size in order to justify commercial development.

Potential reservoir rocks. Sedimentary rocks, mainly of Mesozoic to Tertiary age, are 30,000 feet or more thick. Sandstones and limestones are the major potential reservoir rocks. Limestones are more important in the southern portion of the province and perhaps are more important in the farther offshore areas of the Slope Province.

Traps. A large variety of trapping mechanisms have been postulated to occur, including most principal types of both stratigraphic and structural traps. Carbonate environments, including reefs if present, could include stratigraphic traps due to reef structures and permeability changes. Truncations and pinch outs may be related to some clastic reservoirs. Salt domes are also believed to be present. Structural traps may include both faults and folds.

Potential source rocks. Potential source rocks in the central portion of both provinces are anticipated to be more favorable for natural gas generation than for oil. Prospects for oil generation, along with gas, are more favorable in the northern (Georges Bank) and southern (Southeast Florida Shelf) regions.

P-910 and P-911, ATLANTIC OFFSHORE, SHELF AND SLOPE
Generalized Stratigraphic Section

AGE	FORMATION	
	NORTH	SOUTH
Cenozoic		
Pleistocene	Laurentian Fm.	unnamed sand, silt & clay
Pliocene-Miocene	Banquereau Fm.	
Oligocene-Eocene-Paleocene	unnamed limestone	unnamed mudstone & chalk
Mesozoic		
Cretaceous		
Late	Dawson Canyon Fm.	unnamed siltstone & shale
Early	Missisauga Fm.	unnamed sandstone
	Baccaro Ls.	shale & limestone
Jurassic	Mic Mac-Mohawk Fm.	evaporites
	Mohican Fm.	
	Iroquois Fm.	
Triassic	conglomerate	unnamed sandstone
	Argo Salt	siltstone, shale
Paleozoic and Precambrian	metamorphic complex	

P-915 AND P-916, WEST FLORIDA OFFSHORE, SHELF AND SLOPE

The western Florida Shelf extends about 150 miles into the Gulf of Mexico. Many of the stratigraphic units of onshore peninsular Florida extend into this offshore area. Cretaceous and Tertiary rocks comprise the majority of the 25,000-30,000 feet of sediment in this area. Carbonate rocks are the major constituent in most of the province. Clastic rocks were deposited in the north. Probability is good for continuation of trends from the eastern part of the Gulf Coast Province and the panhandle region of Florida. Additionally, trends that are productive predominantly of oil in south Florida may also extend offshore and include some natural gas resources. No hydrocarbons are presently being produced in the province. The west Florida offshore area is extremely large, and there is virtually no information available from drilling that is applicable to these provinces. If natural gas production is established in the area, it would be anticipated that the fields would be intermediate to large size.

Potential reservoir rocks. The southern part of the province, which lies in the South Florida basin, appears to offer prospects for large-scale production. The Lehigh Acres Formation (Lower Cretaceous) is the best prospect because of the thick and highly porous Brown Dolomite zone in the Twelve Mile Member. The Sunniland Formation, which is productive onshore, will not prove economically feasible offshore unless it has a thicker porous section than is found onshore. Other formations that are of earliest Cretaceous and late Jurassic age may prove productive, but to date the porosity and geochemistry found in these formations onshore have not been favorable.

In the northern portion of the province, there is potential for the extension offshore of the productive trends of southern Mississippi, southern Alabama and northwestern Florida. Possible reservoir units in the area are the Upper Cretaceous Tuscaloosa Formation, the Lower Cretaceous Hosston Formation, and the Upper Jurassic Smackover Formation.

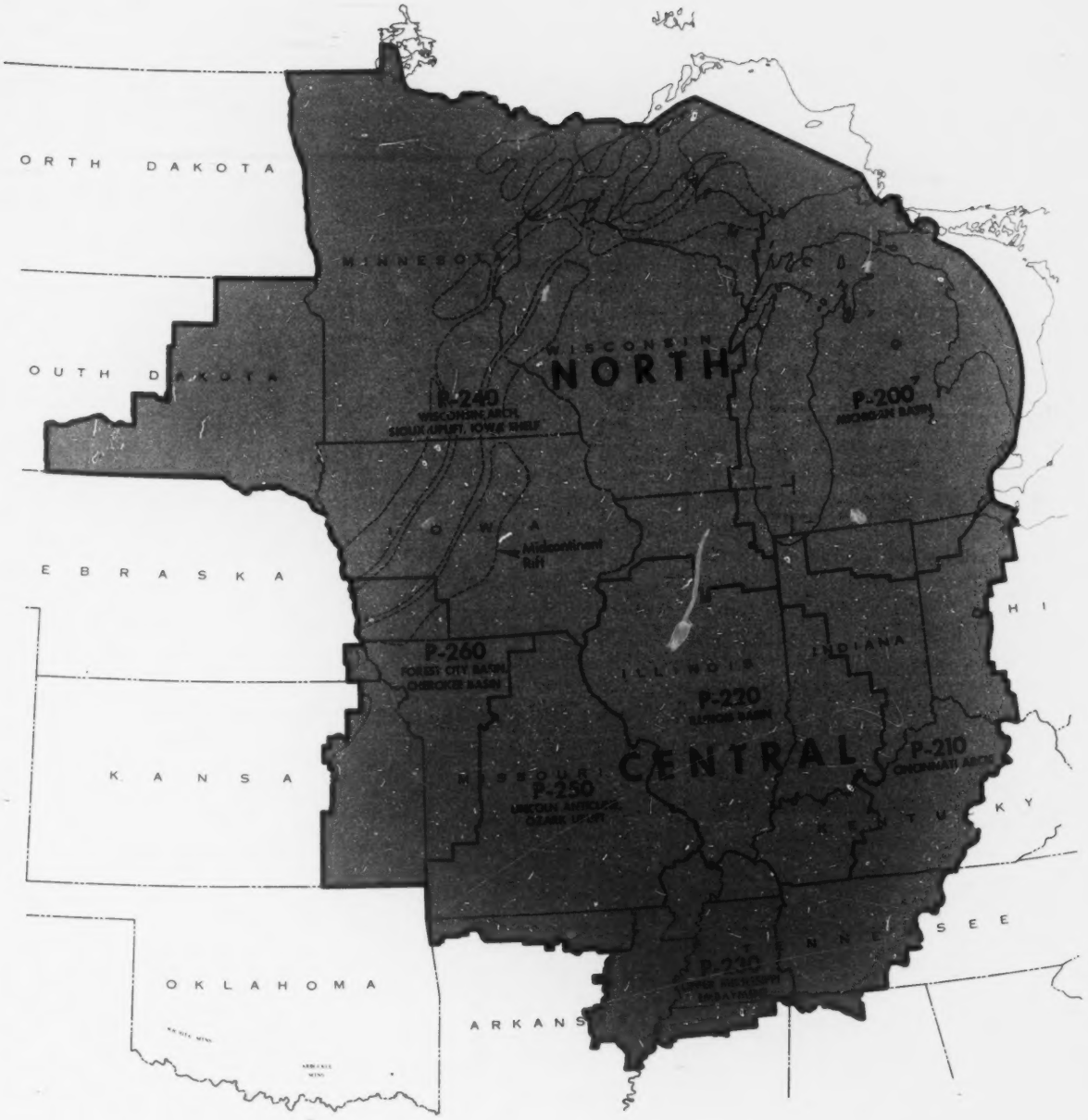
Traps. Possible trapping mechanisms include reefs in the Upper Cretaceous and porosity changes in carbonate and sandstone facies. Anticlines, faulted anticlines and salt domes may exist.

Table 9. Estimated resources of natural gas for provinces of the Atlantic Area, December 1990 (billion cubic feet)

PROVINCE	PROBABLE			POSSIBLE			SPECULATIVE		
	Min.	M. likely	Max.	Min.	M. likely	Max.	Min.	M. likely	Max.
Onshore, less than 15,000'									
P-100, New England and Adirondack uplift							*	650	1,850
P-110, Atlantic Coastal basin							*	450	1,450
P-120, Appalachian basin	14,374	20,473	51,183	3,950	7,500	24,600	5,550	14,650	51,400
P-130, Piedmont-Blue Ridge province							500	2,050	6,000
P-140, South Georgia-Peninsular Florida							*	350	950
P-150, Black Warrior basin	160	450	850	100	300	650	*	450	1,000
Onshore, 15,000-30,000'									
P-100, New England and Adirondack uplift							*	*	*
P-110, Atlantic Coastal basin							*	*	*
P-120, Appalachian basin							820	5,000	16,700
P-130, Piedmont-Blue Ridge province							920	4,550	11,000
P-140, South Georgia-Peninsular Florida							*	500	1,450
P-150, Black Warrior basin				150	400	850	*	2,300	3,300
Offshore, 0-200 m									
P-910, Atlantic shelf							*	13,200	33,000
P-915, West Florida shelf							*	1,600	4,000
Offshore, 200-1,000 m									
P-911, Atlantic slope							*	*	*
P-916, West Florida slope							*	650	6,000
Sum of Most Likely Estimates									
Onshore, 0-15,000'		20,923			7,800			18,600	
Onshore, 15,000 - 30,000'		*			400			12,350	
Onshore, All Depths		20,923			8,200			30,950	
Offshore, 0 - 200 m		*			*			14,800	
Offshore 200 - 1000 m		*			*			650	
Offshore, All Depths		*			*			15,450	
GRAND TOTAL FOR AREA		20,923			8,200			46,400	

*Negligible quantity of natural gas estimated.

Mean values by statistical aggregation	Probable Mean	Possible Mean	Speculative Mean
	29,163	12,833	64,077


ORTH DAKOTA
OUTH DAKOTA
MINNESOTA
WISCONSIN
NORTH
P-240
P-200
IOWA
Midcontinent Rift
EBRASKA
P-260
ILLINOIS
INDIANA
P-220
CENTRAL
P-210
KANSA
MISSOURI
P-250
KY
NNESSEE
P-230
OKLAHOMA
ARKANS

NORTH CENTRAL AREA

The estimated resource potential for the North Central area in the Probable and Possible categories occurs entirely within the Michigan basin. Potential resources in the Speculative category are also estimated to occur in the Michigan basin and, in addition, are postulated for the Cincinnati arch province, the Illinois basin, the Upper Mississippi Embayment and the Forest City-Cherokee basins.

The Michigan basin has good exploratory potential for both structural and stratigraphic traps having small- to intermediate-size accumulations of gas. One or more giant fields are possible. The deep Cambro-Ordovician formations are now being tested in the basin. The Devonian Antrim Shale is being actively exploited as a shallow nonconventional gas resource in the north central part of the basin. Exploration of the Antrim has resulted in a significant increase in the most likely estimate of potential gas resources. Recent evaluation of the Cambro-Ordovician exploration and development activity has resulted in a decrease in the most likely estimates for the play.

The Cincinnati arch province is generally well explored, but has the potential of the occurrence of small accumulations of either structurally or stratigraphically trapped resources. The Illinois basin is a maturely explored oil basin, and potential gas accumulations will likely be small. Many of the larger shallow structures have been tested into the older formations without encouragement. The Upper Mississippi Embayment is an unexplored province with potential for intermediate-sized structural and stratigraphic traps. The Wisconsin arch-Iowa shelf is sparsely explored because of the relatively thin stratigraphic section consisting mostly of Paleozoic rocks. However, the postulated Mid-Continent Rift Zone indicated by geophysical information may contain intermediate to giant-sized structural traps. It has yet to be proven whether natural gas might be found in these traps. The Lincoln anticline-Ozark uplift province is a structurally high area with Precambrian rock outcrops and does not appear to have natural gas potential. The Forest City basin has been moderately drilled and explored. Potential traps may be either structural or stratigraphic with the accumulations of natural gas most likely to be of small size.

P-200, MICHIGAN BASIN

The Michigan basin geologic province includes the state of Michigan and portions of northern Indiana, northwestern Ohio, northeastern Illinois, and eastern Wisconsin. The province is bordered on the north and east by the Canadian border, on the west by the Wisconsin arch and on the south by the Kankakee and Findlay arches. The basin is a nearly circular structural basin. Precambrian crystalline rocks crop out around the northern rim of the basin. Erosion has not uncovered Precambrian rocks around the southern rim, but formations as old as Ordovician are exposed in Ohio and Indiana. In the center of the basin, Precambrian rock lies at a depth of 18,000 feet or more. The youngest widespread bedrock formations are Jurassic and Pennsylvanian sedimentary rocks that occur toward the center of the basin. These bedrock formations are overlain by up to 1,200 feet of glacial deposits. The sedimentary rocks within the basin consist predominantly of Paleozoic carbonate rocks with some sandstones. Production of both natural gas and oil has been established from many fields within the basin.

Since 1929, approximately 44,225 wells have been drilled within the Michigan basin, the majority of which have tested relatively shallow formations (less than 6,000 feet) along anticlinal trends within the central basin area and for Silurian pinnacle reefs along the northern and southern basin rims at depths ranging 3,000-7,000 feet.

The Middle Ordovician St. Peter Sandstone has yielded significant new deep gas reserves in the central basin area. Only 1,695 wells have tested this horizon,

with the majority of these drilled in the shallow, less prospective southern flank of the basin. Approximately 60-65 percent of the known shallow structures in the central basin area have been tested into the Lower Ordovician sands. Potential gas supply for this deep gas play has been significantly reduced because 1) the producing structures have generally been found to be smaller than anticipated; 2) there has been occasional lack of reservoir development on seismically defined structures, and 3) there have been fewer structures found than were anticipated.

The Devonian Antrim Shale gas play has been very active in Michigan with 833 wells having been completed in 1990 alone. The Federal tax credit has made the play economical, and the activity has been concentrated in Otsego and Montmorency Counties in north-central Michigan. This drilling activity has resulted in a significant increase in the potential gas supply estimates for the Antrim Shale.

Generally, the sedimentary rocks shallower than 6,000 feet are in a mature stage of exploration and offer little potential for substantial new gas discoveries. Sedimentary rocks deeper than 6,000 feet offer the greatest potential for new gas discoveries.

The resources included in the Probable category will be found in field development and extensions. Possible gas resources are expected to be found in fields ranging in size from 2-40 Bcf with most of them estimated to be in the 5-20 Bcf range. The resources classified as Speculative are expected to be found in fields ranging from 1-50 Bcf with the most likely size between 5-25 Bcf.

A portion of the Speculative potential for the Michigan basin lies beneath waters of the Great Lakes. These areas are currently withdrawn from exploration and development. The estimated potential for these offshore areas is included within the estimate for the total Michigan basin.

Reservoir rocks. Currently productive and potential reservoir rocks range from the Middle Ordovician (St. Peter) sandstone to the Mississippian (Berea, "Stray" and Marshall sandstones). Dolomite and sandstone are the principal potential reservoir rocks, and all potential reservoirs from the Lower Ordovician to the Carboniferous are already productive of gas or oil. Central basin formations of Silurian, Early Ordovician and Cambrian age, including sandstone and dolomite, are potential reservoirs. Fractured Devonian shale is a significant newcomer on the scene.

Traps. Reefs are common traps in Silurian (Niagara) and in Devonian (Traverse) strata. Porosity and permeability variations also form traps in Ordovician, Devonian and Mississippian-Pennsylvanian lithologies. Anticlines and faulted anticlines form traps in Ordovician, Silurian, Devonian and Mississippian-Pennsylvanian beds. Secondarily dolomitized fracture trends accumulate major oil and gas reserves in Middle Ordovician and Devonian carbonates.

Potential source rocks. Potential source rocks for natural gas are predominantly Devonian shale and carbonate rocks (Antrim and Bell Shales, Traverse Group carbonates). The Salina A1 Carbonate is the most likely source for Silurian reef gas accumulations. The Upper-Middle Ordovician Glenwood Shale is considered the source for upper St. Peter reservoirs, and the shales within the Prairie du Chien are a possible source for the deeper St. Peter reservoirs. The Middle Ordovician Trenton-Black River carbonates are also considered a potential hydrocarbon source.

Producing trends. The Niagaran reef trend, the Albion-Scipio type fracture trends and the St. Peter sands are the principal gas-producing areas to date with the Antrim Shale rapidly increasing in importance. Production generally is from less than 8,000 feet. Gas occurs in the Middle Ordovician St. Peter at depths as great as 11,630 feet primarily along anticlinal trends in the central basin area.

P-200, MICHIGAN BASIN
Generalized Stratigraphic Section

AGE	FORMATION
Paleozoic	
Pennsylvanian	Grand River Fm.
	Saginaw Fm.
Mississippian	Grand Rapids Gp.-
	Michigan Fm.
	* Marshall Ss.
	* Coldwater Sh.
	* Ellsworth Sh.
	Sunbury Sh.
	* Berea Ss.
	Bedford Sh.
Devonian	* Antrim Sh.
	* Traverse Gp.
	Bell Sh.
	* Rogers City-Dundee Ls.
	Detroit River Gp.
	*Lucas Fm.
	Amherstburg Fm.
	Sylvania Ss.
	Bois Blanc Fm.
	Garden Island Fm.
Silurian	Bass Islands Dolo.
	Salina Gp.
	** A-E Units
	* Niagara Gp.
	* Clinton Gp.
	Cataract Gp.
	Cabot Head Sh.
	Manitoulin Dolo.
Ordovician	undiff. Cincinnatian rocks
	Utica Sh.
	* Trenton Gp.
	* Black River Gp.
	Glenwood Sh.
	* St. Peter Ss.
	* Prairie du Chien Gp.
Cambrian	† Trempealeau Fm.
	Munising Fm.
	Franconia Fm.
	Galesville Ss.
	† Eau Claire Fm.
	Mount Simon Ss.
Precambrian	Jacobsville Ss.

* Currently producing
** Some units productive
† Potentially productive

P-210, CINCINNATI ARCH
Generalized Stratigraphic Section

AGE	FORMATION		
	INDIANA	OHIO	KENTUCKY
Cenozoic			
Pleistocene	Martinsville Fm.	tills & outwash	fluvial & outwash with some till
	Prospect-Wedron Fm.		
	Jessup-Atherton Fm.		
Paleozoic			
Pennsylvanian			Caseyville Fm.
Mississippian			* Pennington Fm.
			Bangor Ls.
			Hartsell Fm.
			Monteagle Ls.
			Kidder-Girkin Mbr.
			* Ste. Genevieve Ls.
	St. Louis Ls.		St. Louis Ls.
	Salem Ls.		Salem Ls.
	Harrodsburg Ls.		Harrodsburg Ls.
	Ramp Creek Fm.		
	Borden Gp.		Borden-New Providence Fm.
	Rockford Ls.	Cuyahoga Fm.	Rockford Ls.
Miss.-Devonian	New Albany Sh.		
	Ellsworth Sh.	Sunbury Sh.	
		* Berea Ss.	* Berea Ss.
Devonian	Antrim Fm.	Ohio Sh.	Ohio Sh.
	Muscatatuck Gp.		* Corniferous Gp.
	* N. Vernon-Traverse Fm.	Traverse Fm.	Boyle Dolo.-Beechwood Fm.
	Jeffersonville Fm.	Detroit River Fm.	Jeffersonville Ls.
Silurian		Bass Island Dolo.	Bayley Ls.
	Salina Gp.		
	Wabash Fm.	A-G Units	* Louisville-Brownsport Fm.
	Pleasant Mills Fm.	Lockport Dolo. Gp.	
	Salamonie Dolo.	Tymochtee Dolo.	
	Laurel Mbr.	Guelph-Goat Island Dolo.	* Laurel Dolo.
		Gasport Dolo.	
	Osgood-Stroh Mbr.	Rochester Sh.	Osgood Fm.
	Sexton Creek Ls.	Cataract Gp.	* Brassfield Dolo.
Ordovician	Maquoketa Gp.	undiff. Cincinnatian rocks	Cumberland-Drakes Fm.
	* Trenton Ls.	* Trenton-Lexington Ls.	Lexington Ls.
	* Black River Gp.	* Black River Ls.	High Bridge Gp.
	Platin Fm.		Tyrone-Camp Nelson Ls.
	Pecatonica Fm.		
	Ancell Gp.-St. Peter Ss.	Wells Creek Fm.	Wells Creek Dolo.
Camb.-Ordo.	* Knox Dolo.	* Knox Dolo.	Knox Gp.
			* Beekmantown Dolo.
Cambrian	Franconia Fm.		* Cooper Ridge Dolo.
	Tronton Ss.		
	Galesville Ss.		
	Eau Claire Fm.	Eau Claire Fm.	Conasauga Fm.
	Mount Simon Ss.	Mount Simon Ss.	* Rome Fm.

* Currently producing

P-210, CINCINNATI ARCH

The Cincinnati arch is a wide area of uplift that stretches from Ohio and Indiana southward through Kentucky and Tennessee into northernmost Alabama. The northern portion of the arch splits east and west into two branches that wrap around the southern end of the Michigan basin. The western branch is known as the Kankakee arch and the eastern as the Findlay arch. The southern end of the Cincinnati arch is somewhat separated from the remainder by an area in southern Kentucky known as the Cumberland saddle, in which the axis of the arch plunges downward. The southernmost portion, south of the Cumberland saddle, is known as the Nashville dome. The Appalachian basin lies to the east and the Illinois basin to the west. The Cincinnati arch complex began its major upwarping in the Silurian Period. The crest of the arch is wide, and dips are exceptionally gentle. Most of the accumulations of gas and oil in western Ohio occur along the structurally highest part of the Findlay arch. Sedimentary rocks in the province range in age from Cambrian to Pennsylvanian and are relatively thin. Natural gas and oil production have been established in all the states of this province.

The great Lima-Indiana field of eastern Indiana and western Ohio was discovered in 1884. Maximum production from this field was reached in 1896.

Reservoir rocks. Productive and potential reservoir rocks for gas and oil range in age from Cambro-Ordovician to Mississippian. The most common reservoir rocks are limestone and dolomite. Apart from the Devonian Salina-Niagara Groups, all prospective reservoirs are already productive. The western Ohio fields on the Findlay arch produce chiefly from the Trenton Formation of Ordovician age. Trenton and Black River Limestones (Ordovician) are the principal reservoir formations in northern and eastern Indiana. Silurian carbonate rocks are the most prolific reservoirs in Kentucky, including the Lego (Louisville), Laurel and Brassfield, but production has also been found in Middle Devonian limestone and sandstone, the Ordovician Trenton-Black River-Chazy and the Cambro-Ordovician. Tennessee fields produce from Mississippian, Silurian and Ordovician limestones.

Traps. Production in the Trenton-Black River Limestones is due to irregularly distributed dolomitization porosity enlarged by weathering before subsequent submergence. The principal traps in the Silurian reservoirs of Kentucky occur where porosity zones have been truncated by erosion and sealed by the deposition of the Devonian New Albany (Chattanooga) Shale immediately above the unconformity. Some Ordovician production is from fracture porosity, and there are some reef limestones encased in younger shale. Accumulation in Tennessee appears to be due to varying permeability within the reservoir rocks and to the presence of small folds.

Source rocks. Late Cambrian, Mississippian, and Pennsylvanian shales are considered to be fair to good sources for natural gas.

P-220, ILLINOIS BASIN

This province includes most of the state of Illinois and portions of western Kentucky and Indiana. The province is bounded on the north by the Kankakee arch, on the east by the Cincinnati arch complex and on the south by the Pascola arch. To the west, the basin is bounded by the Mississippi River arch-Lincoln anticline. The province is predominantly an oil-producing province, but some natural gas is produced in small quantities. Sedimentary rocks consist primarily of Paleozoic dolomite, limestone, shale, and sandstone which reach a thickness of at least 20,000 feet in the deepest part of the basin.

Reservoir rocks. Reservoirs for oil and gas exist in rocks of Ordovician to Pennsylvanian age. Lithologies vary from sandstone to limestone and dolomite. Apart from the Devonian New Albany Shale, all potential reservoir rocks are already productive of oil or gas. The principal production comes from Mississippian Chesterian sandstones, Ste. Genevieve, St. Louis and Salem Limestones, Pennsylvanian sandstones, and the Ordovician Trenton-Galena Limestone.

P-220, ILLINOIS BASIN
Generalized Stratigraphic Section

AGE	FORMATION	
	WEST	EAST
Cenozoic		
Quaternary	Peoria Loess	Martinsville Fm.
	Equality-Henry Fm.	Prospect-Wedron Fm.
	Glasford Fm.	Jessup-Glasford Fm.
	Banner Fm.	Banner Fm.
Tertiary	various gravels	various gravels
Mesozoic		
Cretaceous		
Late	Baylis-Tuscaloosa Fm.	
Paleozoic		
Pennsylvanian	McLeansboro Gp.	McLeansboro Gp.
	* Mattoon Fm.	* Mattoon Fm.
	Bond Fm.	Bond Fm.
	* Modesto Fm.	Patoka Fm.
		Shelburn Fm.
	* Carbondale Fm.	* Carbondale Gp.
	Danville Coal Mbr.	Danville Coal Mbr.
	Brereton Ls. Mbr.	Providence Ls. Mbr.
	various coal mbrs.	various coal mbrs.
	* Spoon Fm.	Staunton Fm.
	Browning-Isabel Mbrs.	
	Greenbush Coal Mbr.	Seelyville Coal Mbr.
	various coals & limestones	various coals & limesto
	McCormick Gp.	
	* Abbott Fm.	Brazil Fm.
	* Caseyville Fm.	* Mansfield Fm.
Mississippian	various limes, sand & shale	Buffalo Wallow Gp.
	* Tar Springs Ss.	Tar Springs Ss.
	Okaw Gp.	Stephensport Gp.
	Glen Dean Ls.	Glen Dean Ls.
	* Hardinsburg Ss.	* Hardinsburg Ss.
	* Haney Ls.	Haney Ls.
	* Fraileys Sh.	* Big Clifty Fm.
	* Beech Creek Ls.	Beech Creek Ls.
	Paint Creek-W. Baden Gp.	West Baden Gp.
	* Cypress Ss.	* Cypress-Elwren Ss.
	Cedar Bluff Gp.	* Paoli Ls.
	* Aux Vases Ss.	* Aux Vases Fm.
	* Ste. Genevieve Ls.	* Ste. Genevieve Ls.
	* St. Louis Ls.	* St. Louis Ls.
	* Salem Ls.	* Salem Ls.
	* Ullin Ls.	* Harrodsburg Ls.
	* Warsaw-Ft. Payne Fm.	* Muldraugh Fm.
	Keokuk-Burlington Ls.	* Borden Gp.
	Chouteau Ls.	Rockford Ls.

* Currently producing

P-220, ILLINOIS BASIN (Continued)
Generalized Stratigraphic Section

AGE	FORMATION	
	WEST	EAST
Paleozoic		
Miss.-Devonian	† New Albany Gp.	* New Albany Sh.
Devonian	* Cedar Valley-Lingle Fm.	* N. Vernon Ls.
	* Wapsipinicon-Grand Tower Fm.	* Jeffersonville Ls.
	* Clear Creek Chert	Clear Creek Chert
	Backbone Ls.	* Backbone Ls.
Silurian	* Bailey Ls.	Bailey-Liston Creek Ls.
	* Racine-Moccasin Springs Fm.	Mississinewa Sh.
	Joliet-St. Clair Fm.	St. Clair-Salamonie Dolo.
	* Kankakee-Sexton Creek. Ls.	Sexton Creek-Brassfield Ls.
	* Edgewood Ls.	
Ordovician	Maquoketa Gp.	† Maquoketa Gp.
	* Galena Gp.	* Trenton-Lexington Ls.
	Platteville Gp.	Black River Gp.
	Pecatonica Fm.	Pecatonica Fm.
	Ancell Gp.	Ancell Gp.
	Glenwood Fm.-Joachim Dolo.	Joachim Dolo.
	† St. Peter Ss.-Dutchtown Ls.	† St. Peter Ss.-Dutchtown Ls.
	Everton Dolo.	
	Prairie du Chien Gp.	† Knox Dolo.
	Shakopee Dolo.	
	New Richmond Ss.-Oncota Dolo.	
	Gunter Ss.	
Cambrian	Eminence Fm.	Knox Dolo.
	Potosi Dolo.	
	Franconia Fm.	Franconia Fm.
	Ironton Ss.	Ironton Ss.
	Galesville-Davis Fm.	Galesville-Davis Fm.
	Eau Claire Fm.	Eau Claire Fm.
	Mt. Simon Ss.	Mt. Simon Ss.
Precambrian		

* Currently producing
† Potentially productive

Traps. Although there are many examples of stratigraphic traps in which there is no structural closure and the updip edge of the reservoir is sealed by porosity attenuation, some of the most prolific production in the basin has come from reservoirs in which there is continuous porosity and permeability across the tops of anticlines and other structural highs. Relatively minor fractions of the basin's production is associated with faults and Silurian reefs.

Source rocks. Among the good source rocks for oil and gas are the Devonian-Mississippian New Albany Shale, the Upper Ordovician Maquoketa Shale and the Middle Ordovician Guttenburg Limestone. Potential source rocks of Cambrian to Pennsylvanian age range from immature to very mature.

Coalbed methane. The Illinois basin is a broad structural depression extending over approximately 53,000 square miles in Illinois, southwestern Indiana and western Kentucky. The most significant coal deposits are found in Pennsylvanian strata. The Springfield-Harrisburg (No. 5) and correlative seams in Kentucky and Indiana are the thickest and laterally most extensive seams in the Illinois basin. Typically 4 to 8 feet thick, this seam is present throughout most of the basin. The Herrin coal, only 30 to 130 feet above the Springfield-Harrisburg seam, is the most widely mined in the basin and ranges in thickness from 6 to 15 feet. These two seams occur within 1,500 feet of the surface throughout the basin. Many other significant coal seams are present to depths of 3,000 feet. Coal rank increases from high-volatile C bituminous in the north to high-volatile A bituminous in the southeast corner of the basin. Gas contents in the coals range between 32 and 147 scf/ton. Apart from a small number of gob degasification wells, there is no commercial production of coalbed methane in the Illinois basin. Therefore, potential coalbed methane resources in this basin can only be estimated based on volumetric coal resource and gas content information. Total estimated coal resources is 150 billion tons. The in-place estimate for coalbed methane is between 4.8 and 22 Tcf, with the most likely recoverable estimated to be 2.[illegible] Tcf.

P-230, UPPER MISSISSIPPI EMBAYMENT

This province includes portions of northeastern Kansas, southeastern Missouri, northern Mississippi, western Kentucky and western Tennessee. The province is bounded on the south by the Black Warrior and Desha basins, on the west by the Arkoma basin, on the north by the Illinois basin and on the east by the Nashville dome. No gas or oil production has been established in this region to date. Sedimentary rocks in this province are predominantly Paleozoic sandstones and carbonate rocks, which may reach a maximum thickness of 20,000 feet.

P-240, WISCONSIN ARCH, SIOUX UPLIFT AND IOWA SHELF

This province includes the states of Minnesota and Wisconsin and portions of South Dakota, Iowa and northern Illinois. The province is bounded on the north by the Canadian border, on the east by the Michigan basin, on the south by the Forest City basin, and on the west by the Siouxana and Chadron arches and the Williston basin. No production of natural gas or oil has been established to date. Sedimentary rocks are predominantly Paleozoic carbonate rocks and sandstones and probably are generally less than 15,000 feet thick. Recent exploration interest has been focused on the Mid-Continent Rift Zone, which traverses the province from northeast to southwest. It is postulated that considerable thicknesses of sedimentary rocks were deposited along this tectonic trend in elongate fault-block basins that may contain potential reservoir and source rocks. The faulting associated with the rift zone may have originated in Precambrian time and continued to affect Paleozoic sedimentation as well.

P-250, LINCOLN ANTICLINE AND OZARK UPLIFT

This province includes portions of Missouri and northern Arkansas. It is bounded on the east by the Lincoln anticline-Mississippi River arch, on the south by the Arkoma basin and on the northwest by the Forest City basin. In total, it encompasses an area of more than 53,000 square miles. No production of natural gas or oil has been established. Sedimentary rocks of Paleozoic age predominate. In most places, the section of sedimentary rocks is thin and basement rocks of Precambrian age are not deeply buried.

P-260, FOREST CITY BASIN AND CHEROKEE BASIN

This province includes an area of more than 63,000 square miles and covers portions of eastern Kansas, southeastern Nebraska, southwestern Iowa and northwestern Missouri. It is bordered on the southwest by the Nemaha uplift, on the southeast by the Ozark uplift, and on the east by the Mississippi River arch-Lincoln anticline. Currently nonassociated gas production has been established in the Kansas portion of the Forest City basin and both oil and gas production in the Cherokee basin and the Missouri portion of the Forest City basin. Sedimentary rocks consist mainly of Paleozoic sandstones and limestones which are up to 20,000 feet thick.

Reservoir rocks. Production of natural gas and oil stems dominantly from Mississippian and Pennsylvanian sandstones and carbonate rocks. The Siluro-Devonian "Hunton" Limestone and the Middle Ordovician Viola/Simpson Limestones are productive of oil in the Forest City basin. Potential reservoir rocks range in age from Cambrian to Pennsylvanian. Sandstones and carbonate rocks are equally important as potential reservoirs.

Traps. Stratigraphic and structural traps are small, but equally abundant, in Pennsylvanian and pre-Pennsylvanian reservoirs. Stratigraphic trap types include porosity and lithology changes, onlaps, sandstone lenses, channels and bars. Structural trap types include both anticlines and faulted anticlines.

Potential source rocks. The thermally immature to mature Pennsylvanian Cherokee Shale and some Mississippian shales and limestones are thought to be good potential sources for both natural gas and oil. The same is true for the Devonian-Mississippian Chattanooga Shale, which is thermaliy mature.

P-260, FOREST CITY AND CHEROKEE BASINS
Generalized Stratigraphic Section

AGE	FORMATION	
	WEST	EAST
Paleozoic		
Pennian		
	* Foraker Ls.	
	* Admire Gp.	
	Janesville Sh.	
	Falls City Ls.	
	Onaga Sh.	Indian Cave Ss.
Pennsylvanian	* Wabaunsee Gp.	* Wabaunsee Gp.
	* Shawnee Gp.	* Shawnee Gp.
	* Douglas Gp.	* Douglas-Pedee Gps.
	* Lansing Gp.	* Lansing Gp.
	Kansas Gp.	Kansas Gp.
	Pleasanton Gp.	Pleasanton Gp.
Mississippian	* Marmaton Gp.	* Marmaton Gp.
	* Cherokee Gp.	* Cherokee Gp.
	"Pennsylvanian basal cgl."	Riverton Fm.
		Ste. Genevieve Fm.
		St. Louis Fm.
		Salem Fm.
		Warsaw Fm.
	* Osagean undiff.	Keokuk-Burlington Ls.
	Gilmore City Ls.	Gilmore City Fm.
	Sedalia-Chouteau Fm.	Chouteau Gp.
	Boice Sh.	Boice Sh.
Miss.-Devonian	† Chattanooga Sh.	† Chattanooga Sh.
		Lime Creek Fm.
Devonian	Mid-Devonian undiff.	Callaway Fm.
Siluro-Devonian	* Hunton Gp.	unnamed
Ordovician	Maquoketa Sh.	Maquoketa Sh.
	† Viola-Kimmswick undiff.	Kimmswick Fm.
		Decorah Fm.
	* Simpson Gp.	
	Platteville Ls.	Plattin Fm.
	St. Peter Ss.	St. Peter Ss.
Cambro-Ordovician	Arbuckle Gp. undiff.	Jefferson City Dolo.
		Roubidoux Fm.
		Gasconade Dolo.
Cambrian		Eminence Dolo.
		Potosi Dolo.
		Derby-Doerum Dolo.
		Davis Fm.
		Bonneterre Fm.
	Lamotte Ss.	Lamotte Ss.
Precambrian		

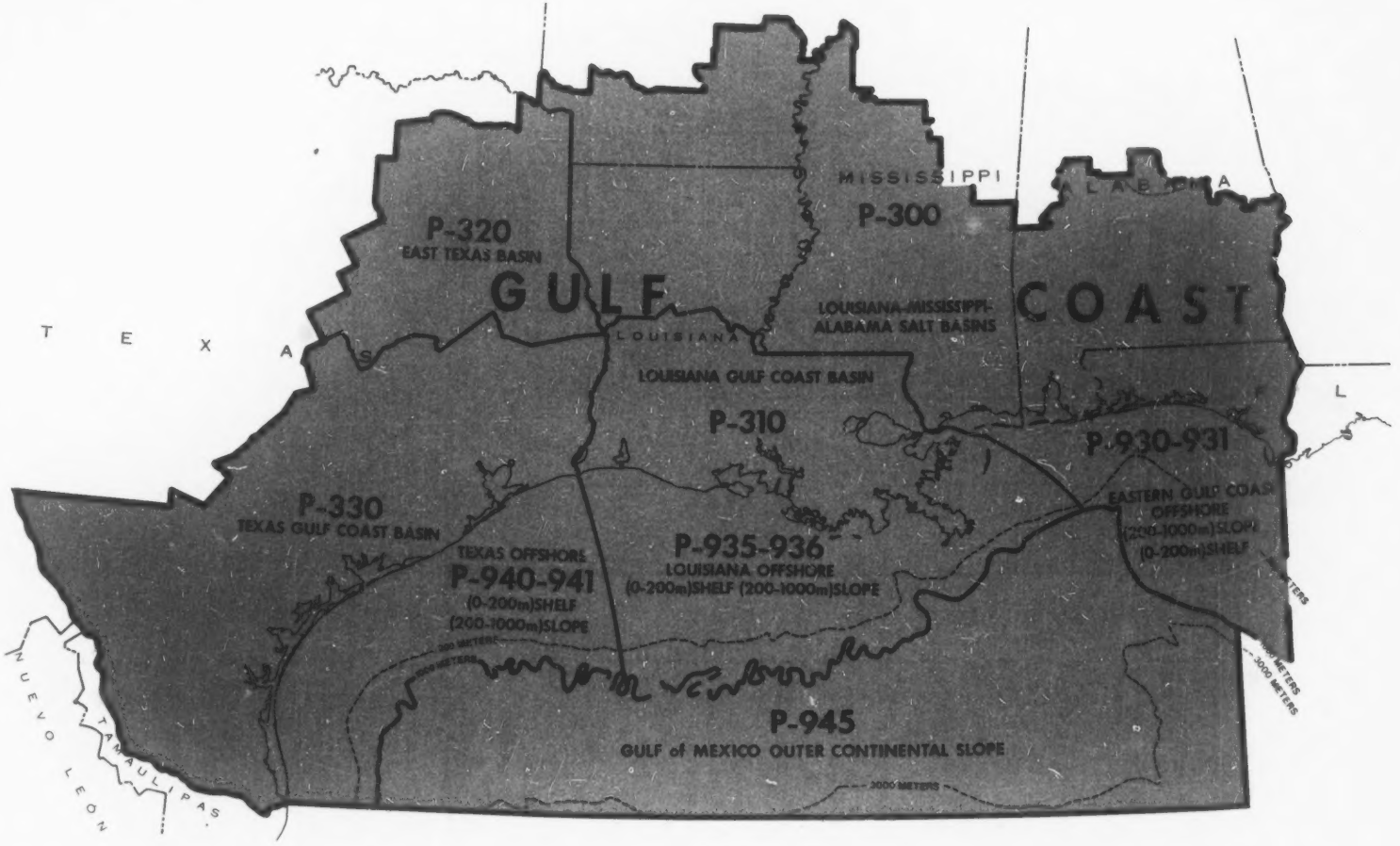
* Currently producing
† Potentially productive

Table 10. Estimated resources of natural gas for provinces of the North Central Area, December 1990 (billion cubic feet)

PROVINCE	PROBABLE			POSSIBLE			SPECULATIVE		
	Min.	M. likely	Max.	Min.	M. likely	Max.	Min.	M. likely	Max.
Onshore, less than 15,000'									
P-200, Michigan basin	108	164	267	2,636	5,229	9,447	66	325	800
P-210, Cincinnati arch							1,428	2,499	7,139
P-220, Illinois basin							1,350	4,900	15,610
P-230, Upper Mississippi Embayment							450	1,450	4,220
P-240, Wisconsin arch, Sioux uplift, Iowa shelf									
P-250, Lincoln anticline, Ozark uplift									
P-260, Forest City basin, Cherokee basin							500	1,000	1,500
Onshore, 15,000- 30,000'									
P-200, Michigan basin							*	*	*
P-210, Cincinnati arch							*	*	*
P-220, Illinois basin							*	*	*
P-230, Upper Mississippi Embayment							*	*	*
P-240, Wisconsin arch, Sioux uplift, Iowa shelf							*	*	*
P-250, Lincoln anticline, Ozark uplift							*	*	*
P-260, Forest City basin, Cherokee basin							*	*	*
Sum of Most Likely Estimates									
Onshore, 0-15,000'		164			5,229			10,174	
Onshore, 15,000 - 30,000'		*			*			*	
Onshore, All Depths		164			5,229			10,174	
GRAND TOTAL FOR AREA		164			5,229			10,174	

*Negligible quantity of natural gas estimated.

	Probable Mean	Possible Mean	Speculative Mean
Mean values by statistical aggregation	180	5,771	14,412


P-320
EAST TEXAS BASIN
GULF
COAST
P-300
LOUISIANA-MISSISSIPPI-ALABAMA SALT BASINS
LOUISIANA
MISSISSIPPI
T E X A S
LOUISIANA GULF COAST BASIN
P-310
P-930-931
EASTERN GULF COAST OFFSHORE
(200-1000m)SLOPE
(0-200m)SHELF
P-330
TEXAS GULF COAST BASIN
TEXAS OFFSHORE
P-940-941
(0-200m)SHELF
(200-1000m)SLOPE
P-935-936
LOUISIANA OFFSHORE
(0-200m)SHELF (200-1000m)SLOPE
200 METERS
3000 METERS
P-945
GULF of MEXICO OUTER CONTINENTAL SLOPE
3000 METERS
NUEVO LEON
TAMAULIPAS

52

GULF COAST AREA

All the geologic provinces of the Gulf Coast Area are potentially productive of natural gas and oil. This region is the dominant producing area of natural gas in the United States. Many of the reservoir rocks are highly porous and permeable and capable of delivering high volumes of gas. A large portion of the major natural gas pipeline system is designed to transport gas from this area to northern and eastern regions of the country. Much of the area is in a mature exploration stage, but important new fields continue to be discovered. The Gulf of Mexico continental slope and the eastern Gulf Shelf are still in the early stages of exploration.

Changes in the estimates of potential gas resources for the Gulf Coast Area primarily reflect transfers from potential resources to proved reserves as the result of continued drilling and discoveries. Poor wildcat success and the abandonment of offshore leases, particularly in the Destin Dome crest, necessitated a reduction in the estimates of Possible and Speculative resources for the Eastern Gulf Offshore Shelf and Slope (P-930 and P-931). On the other hand, the incremental recovery anticipated through horizontal drilling in formations such as the Austin Chalk resulted in a significant increase of the Speculative resource estimate for the Texas Gulf Coast basin (P-330). Generally, the resource estimates have been adjusted to represent a more reasonable distribution among the minimum, most likely and maximum cases.

P-300, LOUISIANA-MISSISSIPPI-ALABAMA SALT BASINS

This region is bounded on the northwest by the Ouachita Mountains, and on the northeast and east by the Paleozoic Black Warrior basin and the southern extent of the Eastern Thrust Belt. North Louisiana contains three structural uplifts: Sabine, LaSalle and Monroe. Northeast-southwest trending faults flank the east side of the Sabine uplift. Other structural elements include Jackson Dome, an igneous intrusion in central Mississippi; the Hatchtigbee anticline; and the Pickens-Gilbertown-Pollard fault zone, which is an extension of the Mexia-Talco fault zone of the East Texas basin. The Hancock ridge, Wiggins uplift, Mobile graben and Conecuh arch are important features in southern Mississippi and Alabama. The region contains more than 80 salt domes and has many other salt-deformation-related features. It is a major producing province of oil, nonassociated gas and associated/dissolved gas. Hydrogen sulfide and carbon dioxide often contaminate natural gas in the Smackover and Norphlet Formations.

The gas found in deeper drilling in older fields, including field extensions and new pool tests, is included in the Probable resource estimates. Possible resources are estimated to be found in new fields ranging in size from 40 to 600 Bcf with an average range of 60 to 100 Bcf. Speculative resources are estimated to occur in fields of 100 Bcf to 1 Tcf, with the most likely field sizes in the range of 200 to 500 Bcf.

P-300, LOUISIANA-MISSISSIPPI-ALABAMA SALT BASINS
Generalized Stratigraphic Section

AGE	FORMATION		
	CENTRAL-N. LOUISIANA	MISSISSIPPI	ALABAMA
Cenozoic			
Pleistocene	Terraces-Alluvium	Terraces-Alluvium	Terraces-Alluvium
Pliocene	Terraces	† Citronelle Fm.	Citronelle Fm.
Miocene	Fleming Fm.	† Pascagoula-Hattiesburg Fm.	* Pensacola Clay
Oligocene	Catahoula Fm.	Catahoula Fm.-Chickasawhay Ls.	* Tampa Fm.-Chickasawhay Ls.
	Vicksburg Gp.	Vicksburg Gp.	
Eocene	Jackson Gp.	* Jackson Gp.	Jackson Gp.
	* Claiborne Gp.	* Claiborne Gp.	† Claiborne Gp.
	* Wilcox Gp.	* Wilcox Gp.	† Wilcox Gp.
Paleocene	Midway Gp.	† Midway Gp.	Midway Gp.
	* "Monroe Gas Rock"		
Mesozoic			
Cretaceous			
Late	* Navarro Gp.-"Monroe Gas Rock"	* Selma Gp.	* Selma Gp.
	* Taylor Gp.		
	* Austin Gp.	* Eutaw-Austin Gp.	* Eutaw Fm.
	Tuscaloosa Gp.	Tuscaloosa Gp.	Tuscaloosa Gp.
	* Lower Tuscaloosa Fm.	* Lower Tuscaloosa Fm.	* Lower Tuscaloosa Fm
Early	* Washita Gp.	* Washita-Fredricksburg Gps.	* Washita-Fredricksburg G
	* Fredricksburg Gp.	* Paluxy Fm.	* Paluxy Fm.
	* Trinity Gp.	* Mooringsport Fm.	* Mooringsport Fm.
		* Rodessa Fm.	* Rodessa Fm.
	* Sligo Fm.	* Sligo Fm.	* Sligo Fm.
	* Hosston Fm.	* Hosston Fm.	* Hosston Fm.
Jurassic	* Cotton Valley Gp.	* Cotton Valley Gp.	* Cotton Valley Gp.
	* Haynesville Fm.	Haynesville-Buckner Fm.	Haynesville Fm.
	* Smackover Fm.	* Smackover Fm.	* Smackover Fm.
	† Norphlet Fm.	* Norphlet Fm.	* Norphlet Fm.
	Louann Salt	Louann Salt	Louann Salt
	† Werner Fm.	Werner Fm.	Werner Fm.
Triassic	† Eagle Mills Fm.	† Eagle Mills Fm.	† Eagle Mills Fm.
Paleozoic	† undifferentiated	† undifferentiated	† undifferentiated

* Currently producing
† Potentially productive

Reservoir rocks. Production ranges in age from Tertiary to Jurassic. Miocene sandstones produce gas in southern Alabama. Oil and gas are found in Eocene sandstone in Louisiana and Mississippi. Upper Cretaceous reservoirs are predominantly carbonates, however, the lower Tuscaloosa Formation produces oil from sandstone. Lower Cretaceous and Jurassic reservoirs include carbonates and sandstone. Some formations, such as the Cotton Valley and Smackover produce from both sandstones and carbonate facies. Oolitic zones form important reservoirs in the Smackover Formation. Eolian sandstones in the Norphlet Formation are the targets of exploration in Lower Mobile Bay, Alabama.

Traps. Trapping in the region is largely associated with salt deformation. This includes salt domes, truncations, sandstone onlap onto structures and anticlines. Fault-related traps are very important around salt domes, the Jackson dome, the east side of the Sabine uplift, and in the Pickens-Gilbertown-Pollard fault zone. Production from fault traps is frequently on the upthrown block. Lenticular sandstones are common throughout the province. Reefs occur in the Washita Group. A major regional unconformity exists between Lower Cretaceous and Upper Cretaceous rocks. Several smaller unconformities also form traps.

Source rocks. Source rocks range in age from Tertiary to Jurassic. Tertiary source rocks are the Claiborne, Wilcox and Midway Groups. Cretaceous source rocks include the Selma Group, Eutaw Formation, Tuscaloosa Group and Hosston Formation. Jurassic source rocks include the Cotton Valley Group, Smackover Formation and downdip facies of the Norphlet Formation.

Trends. Wilcox and lower Tuscaloosa sandstones produce in the southern portion of the province in Louisiana and Mississippi. The chalky carbonates of the Monroe "gas rock" are significant gas producers on the Monroe uplift. The Sligo and Hosston Formations are important gas intervals in the North Louisiana basin. The Hosston is also important in south-central Mississippi. The Cotton Valley and Smackover Formations are prolific in southern Arkansas and northernmost Louisiana and southeast from the Jackson dome along the Pickens-Gilbertown-Pollard fault zone. To date, success in finding production from the Norphlet Formation has been widely scattered along the Smackover trend. However, a remarkable concentration of large gas fields occurs in the Norphlet at depths below 20,000 feet in Lower Mobile Bay, Alabama and adjacent federal waters.

P-310, LOUISIANA GULF COAST BASIN (ONSHORE)

The Louisiana Gulf Coast Basin is one of the major oil and gas provinces in the United States. It is the lower part of the Mississippi Embayment. Most of the province is covered by Quaternary deposits, but Tertiary rocks crop out in the northern portion. An extremely thick clastic wedge of fluvial and deltaic sediments was deposited. Regional structure is largely the result of differential sedimentation related to salt flowage and associated contemporaneous faulting. Salt domes are abundant, and both salt and sulfur are mined.

The South Louisiana onshore basin is one of the most extensively explored areas in the United States. A large percentage of the hydrocarbons found to date above 15,000 feet have been crude oil with dissolved and associated gas caps. Some 90 percent of the significant anticlinal or fault closures above 15,000 feet have been tested by one or more wells.

Gas discoveries in recent years have found fields ranging in size from 2 to 350 Bcf with average size of some 8 Bcf. Size of future discoveries above 15,000 feet will likely average less than the 8 Bcf. Resources classified as Speculative will be found in fields varying in size from 2 to 500 Bcf with average being 30 to 50 Bcf.

Reservoir Rocks. South Louisiana produces from Tertiary through Cretaceous rocks. Tertiary reservoirs are mainly sandstones capped by shale of Miocene, Oligocene and Eocene age. Cretaceous reservoirs are largely oil-bearing carbonates, but significant gas is present in Tuscaloosa sands and Sligo carbonates. The thick Miocene wedge dominates South Louisiana in both oil and gas production.

Traps. The major trapping mechanisms in this province are faulted anticlines and salt domes. A high percentage of these traps are fault-related. Truncations with overlaps influence some reservoirs. Many strati-

P-310, LOUISIANA GULF COAST BASIN (ONSHORE)
Generalized Stratigraphic Section

AGE	FORMATION
Cenozoic	
Pleistocene	various
Pliocene	Citronelle Fm.
Miocene	* Fleming Fm.
	* "Upper Miocene"
	* "Middle Miocene"
	* "Lower Miocene"
Oligocene	* Catahoula Gp.
	* Anahuac Fm.
	* Frio Fm.
	* Vicksburg Gp.
Eocene	Jackson Gp.
	Claiborne Gp.
	* Cockfield Fm.
	Cook Mountain Fm.
	* Sparta Fm.
	Cane River Fm.
	Carrizo Fm.
	* Wilcox Gp.
Paleocene	Midway Gp.
Mesozoic	
Cretaceous	Selma Chalk
Late	Navarro Gp.
	Taylor Gp.
	* Austin Chalk
	Tuscaloosa Gp.
	* Lower Tuscaloosa Fm.
Early	† Washita undiff.
	† Fredricksburg undiff.
	† Paluxy Fm.
	† Trinity Gp.
	Mooringsport Fm.
	* Rodessa Fm.
	Pine Island Fm.
	* Sligo Fm.
	† Hosston Fm.

* Currently producing
† Potentially productive

graphic traps, including updip porosity wedgeouts, occur in the Cretaceous carbonates.

Source rocks. Thick, organic-rich, Cretaceous and Tertiary shale provide ample sources for hydrocarbons in this prolific province.

Trends. Starting with the Lower Cretaceous in the northern portion of the province, the major trends parallel the coastline in bands of progressively younger sedimentary rocks in the following sequence: Lower Tuscaloosa, Wilcox, Oligocene, Lower Miocene, Middle Miocene and Upper Miocene.

P-320, EAST TEXAS BASIN

The East Texas basin, or Tyler basin, occupies northeastern Texas. It is bounded on the north and west by the Ouachita tectonic belt and is separated from the North Louisiana basin to the east by the Sabine uplift. The Angelina-Caldwell flexure separates it from the Texas Gulf Coast basin to the south. The East Texas basin is part of the Mississippi Embayment. Upper Cretaceous rocks crop out in the western and northwestern portions. Progressively younger rocks crop out to the south and east. The two most prominent structural features in the basin are the Mexia-Talco fault system, which parallels the Ouachita tectonic belt on the west and north margins of the basin, and the Sabine uplift to the east. The Mexia-Talco system extends eastward into the Louisiana-Mississippi-Alabama salt basin. The Mt. Enterprise fault system extends westward from the southern flank of the Sabine uplift to near the central portion of the basin. Several regional unconformities occur in this basin. There are also numerous salt domes, salt anticlines and related residual or "turtleback" structures.

The East Texas basin is a maturely explored province. Resources included in the Probable category will be found in field extensions and infield drilling. Possible resources will likely be found in new fields ranging in size from 5 to 50 Bcf. Speculative resources probably will be found in fields from 20 to 500 Bcf.

Reservoir rocks. Production ranges in age from Jurassic to Tertiary. The only Tertiary production is from sandstones of the Wilcox and Claiborne Groups. Upper Cretaceous production is from carbonates in the Taylor and Austin Groups, and sandstone in the Eagleford and Woodbine Groups. Lower Cretaceous reservoir rocks are predominantly carbonates, but sandstones produce in the Paluxy and Travis Peak Formations. Jurassic reservoirs include sandstone and carbonates in the Cotton Valley Group and Smackover Formation. Paleozoic sandstone and carbonates are potential reservoirs in the northern and western portion of the basin.

Traps. Combination structural-stratigraphic traps are very common throughout the province and affect most of the stratigraphic intervals. Anticlines, faulted anticlines and faults are the most common structural mechanisms, particularly in the Woodbine and Smackover. High-energy sand and carbonate facies, in combination with various structures, form traps in the Tertiary, Upper and Lower Cretaceous units and portions of the Jurassic. Reef facies form traps in the James Limestone. Salt domes are less important as traps in the basin. Local and regional unconformities also form traps, the most notable of which is the East Texas field.

Source rocks. The source rocks for this province are probably shales adjacent to the various reservoirs. Carbonates are possible sources in parts of the area, as are transgressive shales overlying unconformities.

Trends. Notable trends include the Mexia-Talco fault zone and the Smackover trend, which generally parallels the Mexia-Talco trend but lies farther downdip. Two Cotton Valley trends occur, one in an arcuate pattern around the western flank of the Sabine uplift, and the other along the southwestern portion of the basin. Most of the major Upper and Lower Cretaceous producing formations occur basinwide and are not situated in trends.

P-320, EAST TEXAS BASIN
Generalized Stratigraphic Section

AGE	FORMATION
Cenozoic	
Pliocene	Goliad Fm.
Miocene	Fleming Fm.
Oligocene-Miocene	Catahoula Fm.
	Vicksburg Fm.
Eocene	Jackson Gp.
	* Claiborne Gp.
	* Wilcox Gp.
Paleocene	Midway Gp.
Mesozoic	
Cretaceous	
Late	Navarro Gp.
	* Taylor Gp.
	* Austin Gp.
	* Eagleford Gp.
	* Woodbine Gp.
Early	* Washita Gp.
	* Fredricksburg Gp.
	* Paluxy Ss.
	* Glen Rose-Rusk Fm.
	Ferry Lake Anhydrite
	* Rodessa-Atascosa Fm.
	Bexar Sh.
	* James Ls.
	Pine Island Sh.
	* Sligo (Pettet) Fm.
	* Hosston (Travis Peak) Fm.
Jurassic	* Cotton Valley Gp.-Schuler Fm.
	* Haynesville-Gilmer Fm.
	Buckner Fm.
	* Smackover Fm.
	Norphlet Fm.
	Louann Salt
	Werner Fm.
Triassic	Eagle Mills Fm.
Paleozoic	† undifferentiated

* Currently producing
† Potentially productive

P-330, TEXAS GULF COAST BASIN (ONSHORE)

The Texas Gulf Coast basin covers 67 counties of southern and southeastern Texas. It encompasses part of the Mississippi Embayment and part of the Rio Grande Embayment. The Balcones fault zone and Ouachita tectonic belt bound the province on the north and west. This is one of the major hydrocarbon regions of the United States. Much of the production comes from Tertiary reservoirs. Both associated/dissolved and nonassociated gas are produced.

Resources classified as Possible are expected to be found in fields from 3 to 30 Bcf with most being in the 10 to 15 Bcf range. Speculative resources are expected to be found in fields varying from 10 to 100 Bcf with the most likely size being 20 to 40 Bcf.

Reservoir rocks. Tertiary sandstones, notably the Frio Formation, dominate production in this province. Upper Cretaceous reservoir units include sandstone and carbonates. Lower Cretaceous sedimentary rocks produce primarily from carbonates. All productive formations produce both oil and gas except the Lower Cretaceous Sligo and Glen Rose Formations, which produce only gas.

Traps. Anticlines, domes, diapirs and faults are the most common trapping mechanisms in the region and affect all productive intervals. Salt diapirs are more common in the northern portion, whereas shale diapirs are more common in the southern portion. Stratigraphic traps are less common, but sandstone lenses, sandstone pinch outs across structures and updip pinch outs do exist in the region. Overpressured reservoirs exist on shallow salt domes as well as at deeper levels. Some Frio structures host in excess of 50 sandstone reservoir units. Reefs occur in the Cretaceous, producing primarily nonassociated gas.

Source Rocks. All intervals from Tertiary to Lower Cretaceous contain likely source rocks. Most of these are bituminous shale, but limestone and chalk are also sources in the region.

Trends. Numerous trends exist in this province. They lie subparallel to both the Ouachita Tectonic belt and the present-day coast and overlap one another. Proceeding from west to east are: the Cretaceous trend, the Wilcox trend, the Queen City-Yegua trend, the Vicksburg-Frio trend and the Miocene trend, which extends offshore. The Cretaceous Edwards reef trend overlaps the Eocene Wilcox trend.

P-330, TEXAS GULF COAST BASIN (ONSHORE)
Generalized Stratigraphic Section

AGE		FORMATION
Cenozoic		
	Pleistocene	various sandstones
	Pliocene	Goliad Fm.
	Miocene	* Lagarto Fm./Oakville-Fleming Fm.
		* "Catahoula" Fm.
		* Anahuac Fm.
	Oligocene	* Frio-Hackberry Fm.
		* Vicksburg Fm.
	Eocene	* Jackson Gp.
		* Claiborne Gp.
		* Wilcox-Sabinetown Fm.
	Paleocene	* Midway Gp.
Mesozoic		
	Cretaceous	
	Late	* Escondido-Navarro Fm.
		* Olmos Fm.
		* Taylor Fm.
		* Austin Chalk
		Eagle Ford Fm.
		* Woodbine Fm.
		* Buda Fm.
		Del Rio Fm.
		* Georgetown Fm.
	Early	* Edwards Gp.
		Glen Rose-Stuart City Fm.
		Pearsall Fm.
		* Sligo Fm.
		† Hosston Fm.
		Cotton Valley Fm.
		Buckner Fm.
		† Smackover Fm.
		† Norphlet Fm.
		Louann Salt
		Werner Fm.
		† Eagle Mills Fm.
Paleozoic		† various shales & sandstones

* Currently producing
† Potentially productive

P-930 and P-931, EASTERN GULF OFFSHORE, SHELF AND SLOPE

The Eastern Gulf Coast Shelf has excellent potential for future discoveries. The probability is high for continuation of trends offshore from Mississippi, Alabama and the Florida panhandle. Commercial discoveries to date have been confined to the area offshore from Mobile Bay.

The resources classified as Possible are expected to be found in fields ranging from 50 to 750 Bcf, with most of them being in the 100 Bcf range. Speculative resources will be found in fields ranging from 50 to 1000 Bcf, with the most likely size being between 100 and 200 Bcf.

Reservoir Rocks. To date, gas reservoirs have been discovered in discontinuous sandstones within the Miocene Pensacola Clay and eolian sandstone of the Jurassic Norphlet Formation. Much of the Jurassic and Cretaceous section above the Norphlet is considered prospective. Speculative reservoirs could exist in sandstone and carbonates, including the Lower Tuscaloosa, Hosston, Cotton Valley and Smackover Formations.

Traps. Anticlines, fault closures, faulted anticlines, deep-seated salt swells and reefs are the most likely traps in this area. Porosity changes and regional unconformities may also form traps.

Source rocks. The most probable source rocks in this region are the Upper Cretaceous Tuscaloosa Group, Lower Cretaceous Gordo Formation, Jurassic Cotton Valley Formation and unrecognized downdip rocks.

P-935 and P-936, LOUISIANA OFFSHORE, SHELF AND SLOPE

This region is the most prolific offshore area of the United States. The shelf is only 20 miles wide at the end of the Mississippi delta but widens to 130 miles near the Texas Gulf Coast boundary. The upper slope, as well as the shelf, is very productive. East-west-trending fault zones extend from onshore out onto the shelf. Pressures encountered in the reservoirs may be much higher than normal.

Reservoir rocks. Reservoir rocks in this area are all sandstone. They range in age from Pleistocene through Miocene. Older units are buried to great depth and are not productive to date. Individual formation names are not applied in the offshore. Paleontological markers are the most commonly utilized means of identifying the stratigraphic units. Many of the units are debris flows and submarine fans.

Traps. Salt domes, growth faults and faulted anticlines are the most common trapping mechanisms in this province. Onlaps and truncations are very common. Porosity changes in the deeper reservoirs and lenticular sand bodies also form effective traps.

Source rocks. The source rocks are bituminous shale ranging in age from Miocene through Pleistocene.

Trends. The Miocene-Pliocene Fleming Trend extends from onshore, continuing offshore, to near the shelf-slope break. The Pleistocene trend starts near the Mississippi River mouth and extends down the continental slope.

P-940 and P-941, TEXAS OFFSHORE, SHELF AND SLOPE

The Texas Offshore portion of the Gulf Coast is an important hydrocarbon-producing province. The majority of production to date has been natural gas, and most of the undrilled prospects are thought to be gas prone. Potential in this region is excellent, but less than that for Offshore Louisiana.

To date, fewer than 6,000 wells have been drilled in the shelf area of 15 million acres, and exploration on the slope is in its early stages. Resources classified as Possible are expected to be found in fields ranging in size from 15 to 400 Bcf, with most of them being in the 20 to 50 Bcf range.

Reservoir rocks. Producing units for the Texas Gulf shelf and slope are sandstones, which are not designated by formation names. They are simply referenced by geologic age or paleontological markers. The productive formations range in age from Oligocene to Pleistocene. Reservoirs produce from as shallow as 1,500 feet to in excess of 15,000 feet.

Since this area is farther from the Mississippi delta complex than Offshore Louisiana, there is a higher percentage of shale in the section, and the sandstones are finer grained. Strong longshore currents during the Tertiary had a destructive effect on the Texas Gulf Coast deltaic deposition with the resulting formation of an extensive barrier-bar system. Quaternary deposits were influenced by sea level fluctuations, with channel and turbidite environments predominant in proximity to the slope. Permeabilities and porosities vary in all age strata because of the diverse depositional environments.

Traps. Anticlines, faulted anticlines, shale diapirs, shallow and deep-seated salt intrusions and growth faults are the major trapping mechanisms. Stratigraphic traps include sandstone lenses, onlap, truncations and porosity variations.

Source rocks. Miocene shales are the probable source rocks for this province. It is hypothesized that vertical migration accounts for the hydrocarbon accumulation in the younger Plio-Pleistocene rocks.

P-945, GULF OF MEXICO OUTER CONTINENTAL SLOPE

The Gulf of Mexico Outer Continental Slope extends downslope from the 1,000-meter boundaries of the Texas, Louisiana and Eastern Gulf slopes to water depths in excess of 3,000 meters at a line extending eastward from the United States-Mexico border.

Although exploration has barely begun in this frontier region, results have been very encouraging so far. Only 20 of the 1,035 active leases have been drilled, yet seven separate discoveries have been recorded by the U.S. Department of the Interior Minerals Management Service. One of these — Shell/Amoco/Exxon's Ram-Powell prospect, which covers eight unitized blocks on Viosca Knoll near the Mississippi Delta — is under planning for development in the near future. Not all results have been favorable, however; reservoir conditions in the Atwater Valley 471-1 have seriously downgraded the apparent potential of one of the major ultradeep-water plays, which materially lowered the maximum resource estimate for this province.

No Proved Reserves have been released yet, and commerciality is yet to be determined for most existing discoveries. Natural gas pipelines currently extend only slightly past the shelf-slope break, leaving many prospects 100 miles from a connection and up to 200 miles from shore. Foreseeable technology will be required to develop and produce discoveries. However, explorationists see Speculative potential for hydrocarbon accumulations large enough to justify development expenditures. Only Speculative resources will be reported until such time as commerciality is established.

Reservoir rocks. Cenozoic sandstones deposited in submarine channels, fans and debris flows are expected to be the principal reservoir rocks. Cretaceous carbonates are also thought to be prospective by some explorationists.

Traps. The total area encompassed by the Gulf of Mexico Outer Continental Slope is greater than the prolific shelves and upper slopes of Offshore Texas and Louisiana combined. A large area within the province is considered to be less prospective due to massive salt accumulations. The salt thins downdip, forming salt-tongue thrusts over younger sedimentary rocks and creating prospects in the resultant folds. Seismic data indicate trap types and trends occurring along the upper slope extend into portions of this province. Salt domes and ridges, fault closures and faulted anticlines are expected to be the principal traps. Stratigraphic factors such as sand pinch outs should also play a significant role in trap formation. Toe thrusts at the basinward extremity of growth faults form faulted anticlines.

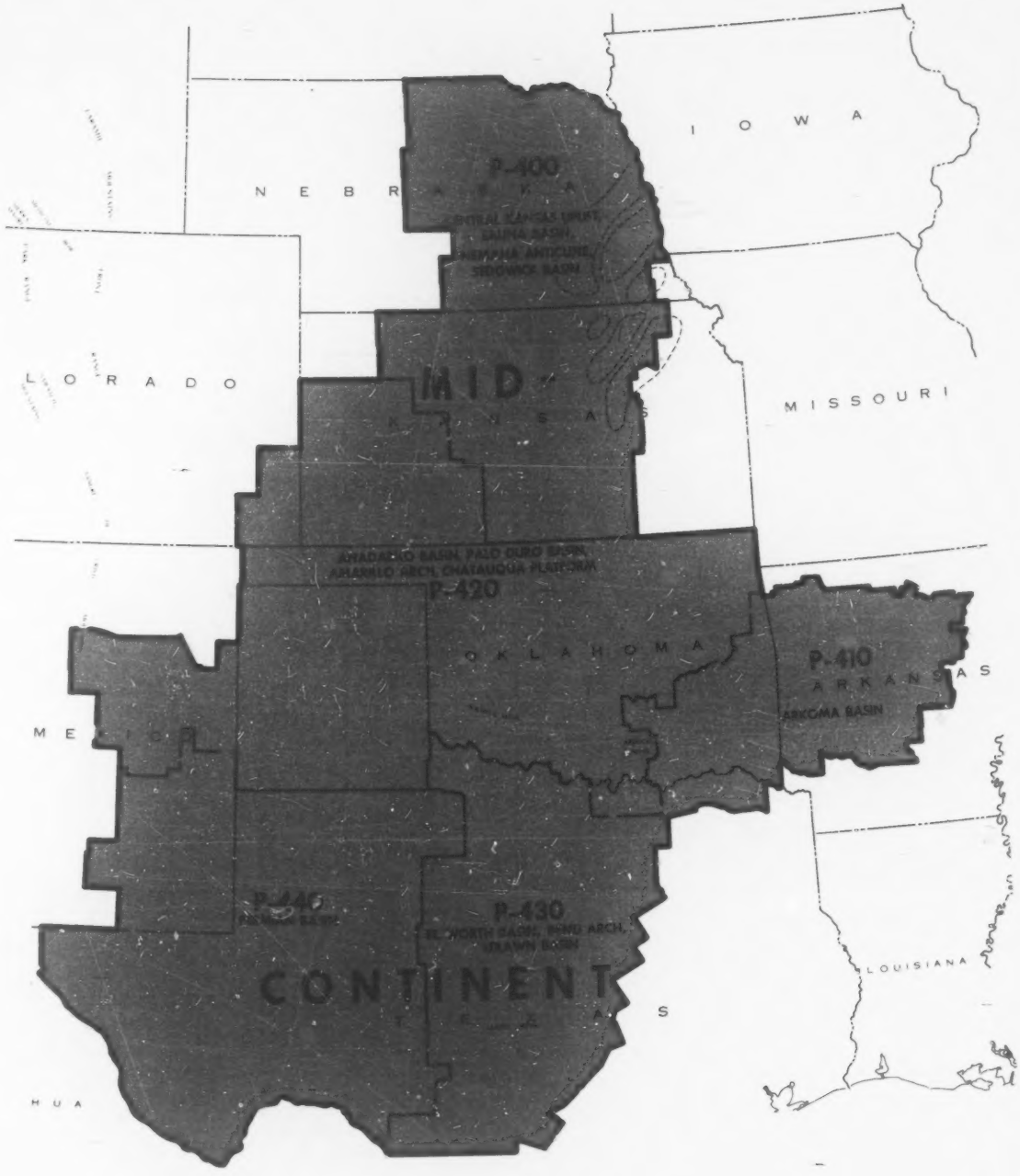
Source rocks. The source rocks are still disputed but are thought to be principally Jurassic and Cretaceous sediments.

Table 11. Estimated resources of natural gas for provinces of the Gulf Coast Area, December 1990 (billion cubic feet)

PROVINCE	PROBABLE			POSSIBLE			SPECULATIVE		
	Min.	M. likely	Max.	Min.	M. likely	Max.	Min.	M. likely	Max.
Onshore, less than 15,000'									
P-300, Louisiana-Mississippi-Alabama salt basins	3,200	4,550	6,650	1,800	3,650	6,100	300	2,800	4,500
P-310, Louisiana Gulf Coast basin (onshore)	1,500	3,210	4,000	500	1,900	3,500	*	*	*
P-320, East Texas basin	1,420	1,790	2,350	975	2,770	6,800	210	390	710
P-330, Texas Gulf Coast basin (onshore)	720	3,500	5,300	3,970	10,870	14,420	880	7,520	47,760
Onshore, 15,000-30,000'									
P-300, Louisiana-Mississippi-Alabama salt basins	450	1,150	1,600	2,800	5,850	9,800	750	10,500	17,250
P-310, Louisiana Gulf Coast basin (onshore)	2,500	3,650	5,000	2,000	6,100	10,500	*	450	1,000
P-320, East Texas basin	50	100	150	50	200	350	100	220	465
P-330, Texas Gulf Coast basin (onshore)	4,100	5,500	7,050	5,150	6,600	9,250	20	140	892
Offshore, 0-200 m									
P-930, Eastern Gulf shelf	2,400	3,600	5,600	900	4,900	17,300	200	6,800	15,200
P-935, Louisiana shelf	6,300	12,900	15,100	4,200	16,200	27,800	*	*	*
P-940, Texas shelf	2,500	5,000	8,100	5,200	11,950	22,500	*	800	2,400
Offshore, 200-1,000 m									
P-931, Eastern Gulf slope	*	*	*	100	2,000	4,800	*	5,700	12,900
P-936, Louisiana slope	400	1,400	2,500	3,700	12,500	22,200	*	*	*
P- 941, Texas slope	25	90	120	2,600	4,100	8,750	160	850	1,500
Offshore, <1,000 m									
P-945, Gulf of Mexico Outer Continental Slope	*	*	*	*	*	*	10,000	30,000	50,000
Sum of Most Likely Estimates									
Onshore, 0-15,000'		13,050			19,190			10,710	
Onshore, 15,000 - 30,000'		10,400			18,750			11,310	
Onshore, All Depths		23,450			37,940			22,020	
Offshore, 0 - 200 m		21,500			33,050			7,600	
Offshore, 200 - 1000 m		1,490			13,600			6,550	
Offshore, <1,000 m		*			*			30,000	
Offshore, All Depths		22,990			51,650			44,150	
GRAND TOTAL FOR AREA		46,440			89,590			66,170	

*Negligible quantity of natural gas estimated.

Mean values by statistical aggregation	Probable Mean	Possible Mean	Speculative Mean
	45,175	95,864	77,806


IOWA
NEBRA
P-400
MID
MISSOURI
ANADARKO BASIN, PALO DURO BASIN,
P-420
OKLAHOMA
P-410
ARKOMA BASIN
P-430
CONTINENT
LOUISIANA

MID-CONTINENT AREA

The Mid-Continent Area is, next to the Gulf Coast Area, the most important area of current natural gas production in the country. The Area includes the Permian basin, the Anadarko basin and the extensive Hugoton-Panhandle area, all of which are important gas-producing areas and have great potential for natural gas exploration and development. Additionally, the Arkoma basin and the Fort Worth basin–Bend Arch–Strawn basin provinces are believed to have significant gas potential.

Almost all the provinces of the Mid-Continent Area are in a mature stage of exploration. It is expected that most future fields to be discovered will fall into small or intermediate size categories. The two exceptions to this generalization are the deeper portions of the Anadarko basin and portions of the Arkoma basin where extensive exploration has not yet occurred.

P-400, CENTRAL KANSAS UPLIFT, SALINA BASIN, NEMAHA ANTICLINE AND SEDGWICK BASIN

This province covers eastern Nebraska and central Kansas. Paleozoic rocks outcrop in much of the region. Lower Cretaceous rocks cover part of the western portion, and Cenozoic rocks mantle parts of Nebraska. It is primarily an oil province, but both nonassociated and associated/dissolved gas is produced. Most of the production in this province is along the Central Kansas uplift. The Salina basin is the least explored portion of the region. (Production is shallow—not more than 5,000 feet deep.)

Reservoir rocks. Producing horizons range in age from Cambrian to Cretaceous. Carbonate rocks of the Cambrian-Ordovician Arbuckle Group contain the major oil reservoirs in the region. Most of the gas, however, is recovered from upper Paleozoic units. Pennsylvanian-age rocks include the Lansing, Kansas City and Cherokee Groups. Permian-age rocks include the Chase, Council Grove and Admire Groups.

Traps. Anticlines, faulted anticlines and domes form traps for all intervals throughout the province. Unconformity truncations affect Pennsylvanian and older units. In the Arbuckle Group, buried topographic relief provides a trapping mechanism. Traps are formed in lower Pennsylvanian units by onlap onto older structures. Variations in porosity affect both carbonate and sandstone units. Sandstones take the form of channel complexes, bars, and sheet sands.

Potential source rocks. The province is dominated by carbonate rocks and shale, which form the source rocks of the area. Most of these are mature, though some of the younger units are immature. All the Pennsylvanian shales and some limestones are considered source rocks. Other known source rocks are the Mississippian Chattanooga Shale and the Ordovician Maquoketa Shale.

P-400, CENTRAL KANSAS UPLIFT, SALINA BASIN, NEMAHA ANTICLINE AND SEDGWICK BASIN
Generalized Stratigraphic Section

AGE		FORMATION
Cenozoic		
Miocene		Ogalalla Fm.
Mesozoic		
Cretaceous	Late	* Niobrara-Ft. Hays Ls.
		† Carlile Sh.
		Greenhorn Ls.
		Graneros Sh.
		† Dakota Gp.
Paleozoic		
Permian	Various	Nippewalla Gp.
	Leonardian	Sumner Gp.
	Wolfcampian	* Chase Gp.
		* Council Grove Gp.
		* Admire Gp.
Pennsylvanian	Virgilian	* Wabaunsee Gp.
		* Shawnee Gp.
		* Douglas Gp.
	Missourian	* Lansing Gp.
		* Kansas City Gp.
		* Pleasanton Gp.
	Des Moinesian	* Marmaton Gp.
		* Cherokee Gp.
	Atokan	Pennsylvanian Basal Cgl.
	Chesterian	
	Morrowan	
Mississippian	Meramecian	Meramecian undiff.
	Osagean	Keokuk Ls.
		Burlington Ls.
		Fern Glen Ls.
	Kinderhookian	Gilmore City Ls.
		Sedalia Dolo.
Devonian	Various	† Chattanooga Sh.
		Middle Devonian undiff.
Silurian	Various	Hunton Gp.
Ordovician	Various	Maquoketa Sh.
		Viola-Kimmswick Ls.
		Platteville Ls.
		* St. Peter Ss.
		* Arbuckle Gp.
Cambrian	Various	Bonneterre Dolo.
		* Lamotte Ss.

* Currently producing
† Potentially productive

P-410, ARKOMA BASIN

This province covers southeastern Oklahoma, western and central Arkansas. It is primarily a gas-producing province. The Oklahoma portion of the province was formerly known as the McAlester coal basin. The Arkoma basin is bounded on the north by the Ozark uplift, on the northwest by the Central Oklahoma platform and Seminole arch, on the west by the Arbuckle Mountains, on the south by the Ouachita Mountains, and on the east by the Mississippi Embayment. It is a Paleozoic basin containing more than 19,000 feet of Pennsylvanian and older rocks.

Most of this province above 15,000 feet has been explored, but some structurally complex areas have not yet been explored extensively. These areas lie in the southern portion of the province. The southeastern portion of the province in Oklahoma is largely untested.

Reservoir rocks. Most of the reservoirs are Des Moinesian to Morrowan in age. Lenticular sandstones of the Atokan Series are the major producers. Both sandstones and limestones of the Morrowan Series form reservoirs in the region. Older units (Ordovician-Silurian) produce oil and gas from sandstone and carbonate reservoirs. Some reservoirs are as shallow as 400 feet.

Traps. Anticlines and faulted anticlines form traps for all intervals. Anticlines in the province are generally large; some are up to 40 miles long and 12 miles wide with up to 3,000 feet of closure. Facies changes associated with channel sands and deltaic complexes are the dominant traps in Des Moinesian and Atokan rocks.

Potential source rocks. All stratigraphic intervals (Ordovician-Permian) provide mature source rocks for the province. Most of these are marine shales, but limestones are sources for some reservoirs.

P-420, ANADARKO BASIN, PALO DURO BASIN, AMARILLO ARCH AND CHATAUQUA PLATFORM

This is one of the major gas-producing provinces of the United States. Much of the gas is nonassociated, but large quantities of oil and associated/dissolved gas are also produced. Nonassociated gas is the main product in the western portion. Oil and associated/dissolved gas are the major constituents in the central and eastern portions of the region. There is very little production in the Palo Duro basin or Wichita Mountains, but the Palo Duro basin has potential for future discoveries.

The Anadarko basin is a northwest-southeast-trending depositional and structural basin. It is bounded on the north by the Cambridge arch-Central Kansas uplift, on the northeast by the Nemaha uplift, on the east by the Arbuckle Mountains, on the south by the Wichita Mountains and Amarillo uplift, on the west by the Cimarron uplift, and on the northwest by the Las Animas arch. The Anadarko basin is highly asymmetrical with the steep side next to the Wichita Mountains. The deeper portion of the Anadarko basin may contain over 40,000 feet of sedimentary rocks. The northwestern end of the basin is called the Hugoton Embayment. The Hugoton-Panhandle field complex covers all or parts of 19 counties in Texas, Oklahoma, Kansas, and Colorado. In the Hugoton area, there are between 2,000 and 7,000 feet of sedimentary rocks.

All rocks overlying the Ordovician in the shallower portions of the Anadarko basin are considered to be mature exploration targets, and it is expected that future new field discoveries would occur in comparatively small stratigraphic traps. Ordovician exploration at depths of 10,000 to 15,000 feet is relatively immature

P-410, ARKOMA BASIN
Generalized Stratigraphic Section

AGE		FORMATION	
		LEHIGH-MCALLESTER BASIN AREA	ARKANSAS BASIN AREA
Paleozoic			
Permian	Wolfcampian	* Pontotoc Gp.	
Pennsylvanian	Virgilian	Ada Fm.	
		Vamoosa Fm.	
	Missourian	Hilltop Fm.	
		Belle City Ls.	
		Francis Fm.	
		Seminole Fm.	
	Des Moinesian	Hoidenville Fm.	
		Wewoka Fm.	
		Wetumka Sh.	
		Calvin Ss.	
		Senora Fm.	
		* Boggy Fm.	* Boggy Fm.
		* Savanna Fm.	* Savanna Fm.
		* McAlester Fm.	* McAlester Fm.
		* Hartshorne Fm.	* Hartshorne Fm.
	Atokan	* Atoka Fm.	* Atoka Fm.
	Morrowan	* Wapanucka Fm.	* Bloyd Fm.
		* Union Valley Fm.	* Hale Fm.
Mississippian	Various	Caney Sh.	Caney equivalent Fms.
Devonian	Various	Woodford Sh.	Chattanooga Sh.
			Sylamore Ss.
			Clifty Fm.
			Penters Chert
		Frisco Fm.	
		Haragan-Bois d'Arc Fm.	
Silurian	Various	* Henryhouse Fm.	* Lafferty Ls.
		Clarita-Quarry Mt. Fm.	St. Clair Ls.
		Cochrane Fm.	Brassfield Ls.
Ordovician	Various	Keel Fm.	Pettit Oolite
		Sylvan Sh.	Cason Sh.
		* Viola Gp.	Fernvale Ls.
			Kimmswick Ls.
		Simpson Gp.	Plattin Ls.
		Fite Fm.	Joachim Dolo.
		* Tyner Fm.	* St. Peter Ss.
		* Burgen Ss.	* Everton Fm.
	Canadian	* Arbuckle Gp.	* Arbuckle equivalents
Cambrian	Trempealeauan-Franconian	* Arbuckle Gp.	
		Timbered Hills Gp.	Elvins Gp.
			Bonneterre Dolo.
			Lamotte Ss.

* Currently producing

overall; most large structures have been drilled, but many smaller structures are untested. It is expected that Ordovician rocks at depths of 10,000 to 15,000 feet may yield small and intermediate-sized fields in the future. The rocks below 15,000 feet in the Anadarko basin are still relatively unexplored, except for localized trends that occur just below 15,000 feet and have reached mature stages of development. Both the Morrowan clastic rocks and the older pre-Mississippian carbonate rocks below 15,000 feet in the Anadarko basin may contain undiscovered fields, with natural gas accumulations of over 40 billion cubic feet per field.

Reservoir rocks. Producing formations range in age from Cambrian to Permian. The major reservoirs are mostly the Permian Leonardian and Wolfcampian Series rocks. Sandstone, conglomerate, limestone, and dolomites are all present in these series. Wolfcampian carbonates of the Chase, Council Grove, and Admire Groups are the major reservoirs in the Hugoton field. Other important reservoirs in western Oklahoma and the Panhandle region include the Silurian Hunton and the Mississippian Chester. In central Oklahoma, the Atokan and Morrowan Series contain important sandstone and limestone reservoirs. Other reservoirs include the Viola Limestone, Simpson Sandstone and the Cambro-Ordovician Arbuckle Group.

Traps. In most of the province, anticlines and faulted anticlines are important trapping mechanisms for Permian and older rocks. In the Palo Duro basin, anticlines affect all productive intervals. Morrow sandstones consist of channel sandstones, delta complexes and littoral sand packages. Variations of permeability and updip pinch outs of permeability form common traps. In the Arbuckle, some units have vuggy porosity development within tighter matrix rocks. Unconformities truncate some reservoirs. Evaporites form seals for part of the Amarillo uplift. The potential for hydrodynamic traps is evidenced by tilting of oil/water and gas/oil contacts in some fields.

Potential source rocks. Source rocks are good to excellent in this province. They range from immature to overmature depending on burial depth. Probable source rocks include all Carboniferous shales and limestones. Another likely source rock is the Devonian Woodford Shale.

P-430, FORT WORTH BASIN, BEND ARCH AND STRAWN BASIN

This province covers the central portion of Texas. It is bounded on the east by the Ouachita tectonic belt and on the south by the Balcones fault zone. It is primarily a Paleozoic province, and Paleozoic rocks crop out at the surface in the northern portion of the province. Lower Cretaceous rocks cover the Paleozoic sedimentary rocks in the southern portion of the province. The province contains no giant fields. Exploration and development costs are low in the region due to shallow production (depths of 1,300 to 6,000 feet). This makes it an attractive drilling area. Both oil and gas are produced in this province, and the gas occurs as both associated-dissolved and nonassociated gas.

Reservoir rocks. Reservoir rocks range in age from Cambrian to Permian. Permian reservoirs include both sandstone and limestone of the Wolfcampian and Leonardian Series. Limestone, sandstone and conglomeratic rocks form reservoirs in Pennsylvanian-age units. Productive Carboniferous units include the Canyon, Strawn, and Atoka Groups. Mississippian reservoirs are limestones of the Barnett and Chappell Formations. Ordovician reservoirs are the Viola, Simpson, and Ellenburger Formations.

Traps. Anticlinal trapping is important in this province. Some anticlines are very large but have low relief; closure may be only tens of feet, but fields may cover many square miles. Some anticlines developed continuously through the deposition of many units and the formation of many unconformities, thus involving many pay zones. Eroded high-relief anticlines form traps for Cambrian and Ordovician units in some areas. Faulted anticlines are a common trapping mechanism in all intervals. Faults are important for some Cambrian oil accumulations. Many unconformities are present in the region and form updip seals for some fields. Stratigraphic traps include sandstone lenses and pinch outs. Reefs and reefal facies are common. Fracture porosity forms traps in some Lower Pennsylvanian carbonates. Combination traps are common.

P-420, ANADARKO BASIN, PALO DURO BASIN, AMARILLO ARCH AND CHATAUQUA PLATFORM
Generalized Stratigraphic Section

AGE		TEXAS-OKLAHOMA PANHANDLE	CENTRAL-WEST OKLAHOMA
Cenozoic			
Pliocene		Ogalalla Fm.	Ogalalla Fm.
Mesozoic			
Cretaceous			
Paleozoic			
Permian	Ochoan	Doxey Fm.	Quartermaster Gp.
	Ochoan-Guadalupian	Cloud Chief Fm.	Cloud Chief Fm.
		Whitehorse Gp.	Whitehorse Gp.
		Dog Creek Sh.	Dog Creek Sh.
		Blaine Fm.-evap.	Blaine Fm.
		Flowerpot Sh.	Flowerpot Sh.
		Glorieta Ss.	Duncan Ss.
	Leonardian	* Clear Fork Gp.	Enid Gp.
		Wellington Fm.	Wellington Fm.
	Wolfcampian	* Chase Gp.	Chase Gp.
		* Council Grove Gp.	Council Grove Gp.
Pennsylvanian	Virgilian	Admire Gp.	Admire Gp.
		* Wabaunsee Gp.	* Wabaunsee Gp.
		* Shawnee Gp.	* Shawnee Gp.
		* Douglas Gp.	* Douglas Gp.
	Missourian	* Lansing Gp.	† Ocheleta Gp.
		* Kansas City Gp.	† Skiatook Gp.
		* Pleasanton Gp.	
	DesMoinesian	* Marmaton Gp.	* Marmaton Gp.
		* Cherokee Gp.	* Cherokee Gp.
	Atokan	Atoka Gp.	* Atoka Gp.
	Morrowan	* Morrow Fm.	* Morrow Fm.
			* Springer Fm.
Mississippian	Chesterian	* Chester Gp.	* Chester Gp.
	Meramecian	"Meramec Lime"	"Meramec Lime"
	Osagean-Kinderhookian	"Osage Lime"	"Osage Lime"
	Various	Woodford Sh.	Woodford Sh.
Silurian	Various	* Hunton Gp.	* Hunton Gp.
Ordovician	Various	Sylvan Sh.	Sylvan Sh.
		Viola Fm.	* Viola Fm.
		Simpson Gp.	* Simpson Gp.
		Arbuckle Gp.	* Arbuckle Gp.
Cambrian		Reagan Ss.	Reagan Ss.
		metasediments	metasediments

* Currently producing
† Potentially productive

Potential source rocks. Carboniferous units are the most common source rocks, and they are all mature. They include the Smithwick Shale, the Strawn Group, and the Mississippian Barnett Formation. Limestones in the region are additional possible source rocks.

P-440, PERMIAN BASIN

The Permian basin covers approximately 76,250 square miles and includes 51 counties in west Texas and four counties in southeastern New Mexico. All but six of these counties are currently productive of oil or gas, and the basin is a major oil and gas (both associated/dissolved and nonassociated) province. Lea County, New Mexico, is one of the richest oil-producing counties in the state.

The basin is bounded on the east by the Bend arch, on the north by the Amarillo-Ouachita uplift, on the west by the Sacramento Mountains, on the southwest by the Diablo platform, and on the south by the Marathon thrust belt.

Sedimentary rocks within the basin are up to 30,000 feet thick in the deepest parts of the basin. Nearly all the rocks are of Paleozoic age with a thin veneer of Mesozoic rocks at the surface. Carbonate rocks, both limestone and dolomite, are the dominant lithology. Thick bituminous shale and lenticular sandstone are interspersed with the carbonate rocks. Thick evaporite sequences were deposited during Late Permian time.

Reservoir rocks. Reservoir rocks for oil and gas range in age from Cambrian through Cretaceous. Carbonate rocks form most major reservoirs, although lenticular sandstones produce in parts of the basin. Most production comes from the thick Permian section. Late Permian Guadalupian rocks, the shallowest reservoirs, have produced more than one-half of the oil produced to date in the basin. The Grayburg and San Andres Formations are the most prolific reservoir formations. Other important reservoirs are: Yates Formation, Glorieta Sandstone, Wolfcampian limestones, Cisco Group, Canyon Group, Strawn Group, Siluro-Devonian carbonates and Ellenburger Dolomite. Porosity ranges from vuggy to cavernous in shallower reservoirs to fracture porosity in deeper reservoirs and low permeability, tight, gas sands.

Traps. The major trapping mechanism in the province is anticlinal folds. Most anticlinal fields produce from several stacked reservoirs, some containing as many as 11 pay zones. The anticlines vary in size, but can be up to 16 miles by 6 miles (Eunice-Monument field). Reef and biohermal facies are the second most common trap. This includes the Capitan reef (Guadalupian). The third most common trapping mechanism is the updip pinch out of lenticular sandstone bodies. Fault traps are rare. Some slump blocks form traps. In some parts of the province, buried topographic highs form traps. Seals in the province include evaporites, shale and porosity loss due to facies changes within the carbonates.

Potential source rocks. Bituminous shales were deposited in the basin during Ordovician, Devonian, Carboniferous and Permian (Wolfcampian, Leonardian) time. These include the Woodford Shale, Barnett Shale, and Simpson Group. The shales are likely source rocks as are numerous carbonate facies throughout the province. All the source rocks in the province are mature.

Future exploration. Present exploration is concentrated in the major producing areas. Gas exploration in the deeper portions of the Delaware and Val Verde basins is very promising. The Abo and Capitan reef complexes need further investigation. Additionally, since the majority of fields are contained in the Guadalupian rocks, all the other known reservoir levels need further examination. The Ellenburger Formation and underlying Cambrian sandstones are good prospective targets.

P-430, BEND ARCH, FT. WORTH BASIN, STRAWN BASIN
Generalized Stratigraphic Section

AGE		FORMATION	
		WEST	EAST
Mesozoic			
Cretaceous	Late		Austin Gp.
			Eagleford Fm.
			Woodbine Fm.
	Early	Segovia Fm.	Washita Gp.
		Fort Terrett Fm.	Fredricksburg Gp.
		Trinity Gp.	Trinity Gp.
Jurassic			
Triassic			
Paleozoic			
Permian	Leonardian	Clear Fork Gp.	
		Wichita Gp.	
	Wolfcampian	Putnam Fm.	
		Moran Fm.	
		Camp Colorado Ls.	
		Pueblo Fm.	
		Harpersville Fm.	
Pennsylvanian	Virgilian	Thrifty-Graham Fms. undiff.	
		* Canyon Gp.	
		* Strawn Gp.	* Strawn Gp.
		Smithwick Sh.	Smithwick Sh.
		* Marble Falls-Dornick Hills Gp.	* Marble Falls Fm.
Mississipppian	Various	Barnett Fm.	Barnett Fm.
		* Chappell Ls.	
Devonian	Various	Houy Fm.	
Silurian			
Ordovician	Various	Viola Gp.	
	Champlainian	Simpson Gp.	
	Canadian	* Ellenburger Gp.	* Ellenburger Gp.
Cambrian	Various	Moore Hollow Gp. (Reagan)	Moore Hollow Gp.

* Currently producing

P-440, PERMIAN BASIN
Generalized Stratigraphic Section

AGE		CARLSBAD-NORTH SHELF	BASIN-PLATFORM	EASTERN SHELF
Mesozoic				
Cretaceous	Early	* Edwards Ls.	* Edwards Ls.	* Edwards Ls.
			* Comanche Peak Ls.	* Comanche Peak Ls.
			* Paluxy Ss.	* Paluxy Ss.
		* Trinity Ss.	* Trinity Ss.	
Jurassic				
Triassic		Chinle Fm.	Chinle Fm.	Chinle Fm.
		Santa Rosa Ss.	Santa Rosa Ss.	Santa Rosa Ss.
		Tecovas Fm.	Tecovas Fm.	Tecovas Fm.
Paleozoic				
Permian	Ochoan	Dewey Lake Fm.	Dewey Lake Fm.	Dewey Lake Fm.
		Rustler Fm.	Rustler Fm.	Rustler Fm.
		Salado Fm.	Salado Fm.	Salado Fm.
			* Delaware Mt. Gp.	
	Guadalupian	Capitan Reef-Carlsbad Ls.-	Belle Canyon-	Artesia Gp.
		Artesia Gp. (North)	Artesia Gp. (East)	Tansil Anhydrite
		Tansil Fm.	Tansil Anhydrite	* Yates Fm.
		* Yates Fm.	* Yates Fm.	* Seven R. Fm.
		* Seven Rivers Fm.	* Seven Rivers Fm.	* Queen Ss.
		* Queen Ss.	* Queen Ss.	
		Goat Seep Reef-	Cherry Canyon Gp. (West) -	
		* Grayburg Fm.	* Grayburg Fm. (East)	* Grayburg Fm.
		* San Andres Dolo.	* San Andres Dolo.	* San Andres Fm.
		* Glorieta Ss.	† Brushy Canyon-	San Angelo Ss.
			* Glorieta Ss.	
	Leonardian	* Yeso Dolo.-varies North	Bone Spring Ls.-	Choza Fm.
		* Abo Sh.-Clyde Fm.	* Clear Fork Gp.	Vale Fm.
		* Abo Shale-Belle Plains Fm.		Arroyo Fm.
				Lueders Fm.
				Clyde Fm.
				Belle Plains Fm.
	Wolfcampian	Hueco Ls.-Hueco equiv.	* Wolfcamp Gp.	Admiral Fm.
				Putnam Fm.
				Moran Fm.
		Powow Cgl.-Pueblo Fm.	"detrital conglomerates"	Pueblo Fm.
Pennsylvanian	Virgilian	* Virgil Gp.	* Cisco Gp.	* Cisco Gp.
	Missourian	* Missouri Gp.	* Canyon Gp.-Scurry Reef Ls.	* Canyon Gp.
	Des Moinesian	* Des Moines Gp.	* Strawn Gp.	* Strawn Gp.
	Atokan	* Atoka Gp.	* Atoka-Bend Gps.	* Bend Gp.
	Morrowan	Morrow Gp.	Morrow Gp.	
Mississippian	Chesterian	Helms Fm.	Helms Fm.-Barnett Sh.	
	Meramecian	Rancheria Fm.	Rancheria Fm.	† Mississippian Ls.
	Chatauquan	Woodford Sh.	Woodford Sh.	
	Various		Thirtyone Fm.	
Devonian	Various	"Silurian Ls."	* Wristen Fm.	
		Fusselman Dolo.	* Fusselman Dolo.	
Silurian	Various	Montoya Dolo.	Montoya Dolo.	
			Simpson Gp.	
Ordovician	Canadian	Ellenburger Dolo.	* Ellenburger-Wilburns Fms.	* Ellenburger-Wilburns Fms.
Cambro-Ordo.		† Bliss Ss.		Cambrian ss.

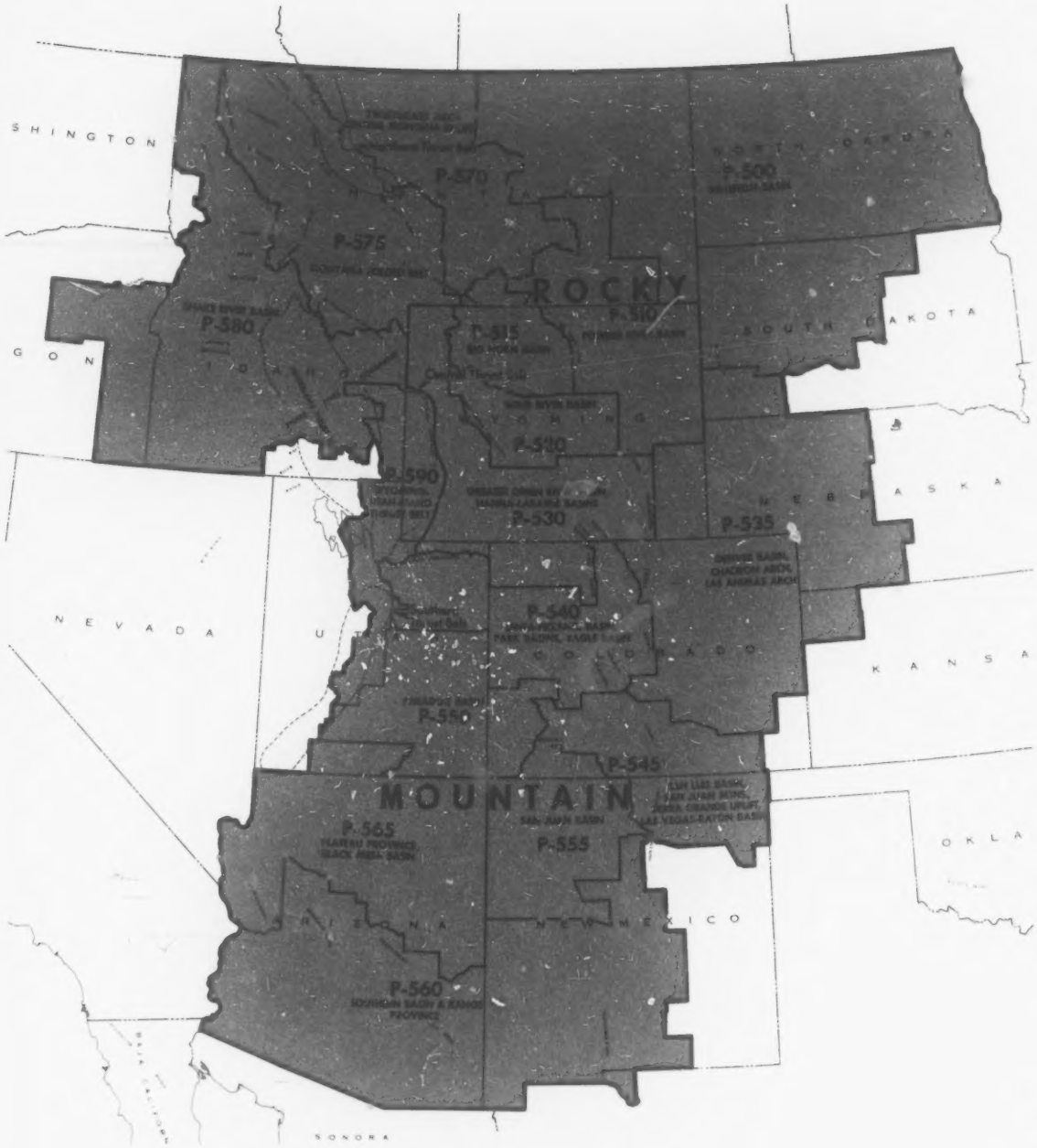
* Currently producing
† Potentially productive

Table 12. Estimated resources of natural gas for provinces of the Mid-Continent Area, December 1990 (billion cubic feet)

PROVINCE	PROBABLE			POSSIBLE			SPECULATIVE		
	Min.	M. likely	Max.	Min.	M. likely	Max.	Min.	M. likely	Max.
Onshore, less than 15,000'									
P-400, Central Kansas uplift, Salina basin, etc.	300	400	600	100	100	200	*	*	*
P-410, Arkoma basin	2,556	3,244	3,966	1,731	2,315	3,191	1,364	1,881	2,473
P-420, Anadarko basin, Palo Duro basin, etc.	10,450	16,100	26,300	8,400	14,950	27,000	10,800	20,100	39,100
P-430, Ft. Worth basin, Bend arch, Strawn basin	1,500	2,000	2,850	900	1,500	2,400	100	500	1,000
P-440, Permian basin	3,400	6,099	10,200	9,500	19,129	30,400	800	1,007	1,700
Onshore, 15,000- 30,000'									
P-400, Central Kansas uplift, Salina basin, etc.							*	*	*
P-410, Arkoma basin	200	300	350	250	400	500	300	500	650
P-420, Anadarko basin, Palo Duro basin, etc.	4,800	8,300	16,100	5,400	9,400	18,300	2,300	4,100	8,100
P-430, Ft. Worth basin, Bend arch, Strawn basin							*	*	*
P-440, Permian basin	4,200	7,500	12,600	8,000	13,378	20,500	*	*	*
Sum of Most Likely Estimates									
Onshore, 0-15,000'		27,843			37,994			23,488	
Onshore, 15,000 - 30,000'		16,100			23,178			4,600	
Onshore, All Depths		43,943			61,172			28,088	
GRAND TOTAL FOR AREA		43,943			61,172			28,088	

*Negligible quantity of natural gas estimated.

	Probable Mean	Possible Mean	Speculative Mean
Mean values by statistical aggregation	48,106	65,981	32,258


SHINGTON
P-570
P-575
P-580
ROCKY
P-500
P-510
P-515
SOUTH DAKOTA
G O N
I D A H O
P-520
P-590
P-530
N E B R A S K A
P-535
NEVADA
U
P-540
C O L O R A D O
K A N S A
P-550
P-545
MOUNTAIN
P-555
P-565
OKLA
A R I Z O N A
N E W M E X I C O
P-560
SONORA

ROCKY MOUNTAIN AREA

The greatest potential for nonassociated natural gas in the Rocky Mountain Area is concentrated in southwestern and central Wyoming and adjacent northwestern Colorado and northeastern Utah. This region includes the Greater Green River basin, the Uinta-Piceance basins and, to a lesser extent, the Wind River basin. All these basins have a Tertiary and Cretaceous section containing large volumes of carbonaceous and coaly sedimentary rocks in addition to marine rocks. Below a depth that generally corresponds to the 200°F isotherm, the sedimentary rocks tend to be overpressured because gas is being generated and cannot escape from the low-permeability rocks. The primary criterion for locating commercial gas production is finding a reservoir that is porous, permeable and continuous. Much of the gas that has been and will be found is in reservoirs classified as "tight." The western Green River basin also includes the multi-trillion cubic foot accumulation of gas with low hydrocarbon content, and hence, low Btu value, found in Paleozoic sedimentary rocks on the Moxa arch. A comparable, somewhat smaller accumulation with a higher Btu gas, has been located below 23,000 feet depth on the Madden anticline in the Wind River basin. Development of this ultradeep field is continuing. The most significant gas activity in the Uinta-Piceance basin area during the past two years involves efforts to produce gas from Upper Cretaceous coalbeds. Although some success has occurred at several locations in the Piceance basin, the eventual level of success and impact upon gas supply is still uncertain.

The second province with major natural gas potential in the Rocky Mountain Area is the Wyoming-Utah-Idaho Overthrust Belt. Large accumulations have been found in the Fossil basin area located in the southwestern corner of Wyoming and adjacent northern portions of Utah. The fields are primarily on the hanging wall of the Absaroka Thrust, where early Mesozoic and Paleozoic reservoirs involved in complexly faulted anticlines have been thrust eastward over Cretaceous source rocks. The Mesozoic reservoirs tend to contain sweet gas and condensate, whereas the Paleozoic reservoirs tend to contain sour gas and condensate. Reservoir rocks have been thrust over Cretaceous sedimentary rocks in other portions of this province. However, there has been sufficient exploratory drilling to show that numerous major accumulations comparable to those in the Fossil basin are not likely to exist throughout the trend. The potential for gas derived from other possible source rocks and for production from Cretaceous sedimentary rocks is still uncertain.

The Montana Folded Belt may contain accumulations resulting from geologic relationships grossly comparable to those existing, and postulated to exist, in the Wyoming-Utah-Idaho Overthrust belt. The Sweetgrass arch and Central Montana uplift province contain numerous accumulations of associated and nonassociated gas in a wide variety of structural and stratigraphic traps involving Paleozoic and Mesozoic reservoirs. The geologic variations found within this province provide opportunity for additional potential gas resources.

The Williston basin is primarily an oil province with most gas reserves and resources in the associated/dissolved category. Deeper accumulations within the basin tend to have higher gas/liquid ratios.

The Powder River basin of eastern Wyoming and Montana is also primarily an oil-producing province with production from Permo-Pennsylvanian and Cretaceous reservoirs. However, ten fields including Hilight, Kitty, Lance Creek and Powell have produced, in aggregate, more than 850 Bcf of associated gas. Recent discoveries at North Buck Draw and Derrick Draw have provided additional excellent oil and gas production from Cretaceous Dakota and Muddy Sandstones, while coalbed methane production from the Tertiary Ford

Union and Wasatch formations is becoming significant. The Big Horn basin of Wyoming and Montana has potential for significant gas accumulations, primarily in Cretaceous sedimentary rocks in the central, deeper portions of the basin, though current production is primarily oil from Paleozoic reservoirs around the margins of the basin.

Most of the gas in the Denver basin is contained in multipay Cretaceous sediments from the greater Wattenberg area north of Denver. This accumulation from stacked low-permeability reservoir rocks occurs over a 4,000 foot vertical interval, from a basin-centered stratigraphic trap. The areal extent of the accumulation is expected to expand north and south along the Denver basin axis. The development of additional gas resources is anticipated from the Lower Cretaceous "J" Sandstone and underlying Plainview-Lytle Formations and from Upper Cretaceous Niobrara, Codell-Timpas, Terry and Hygiene units plus additional associated gas from conventional "D" and "J" sandstone accumulations. Speculative resources are projected in younger Upper Cretaceous formations and in Paleozoic sedimentary rocks. A very interesting play has been aimed at horizontal drilling for fractured Niobrara chalks along the basin axis. A few horizontal wells have been drilled, and numerous more are planned. Where the Niobrara, which contains rich source rocks, is thermally mature, large volumes of associated gas are possible.

The overlapping, multipay accumulations of gas in Upper Cretaceous sandstones that characterize the San Juan basin constitute the largest known conventional gas reserve in the Rocky Mountain Area. During just the past five years, Upper Cretaceous Fruitland Formation coalbeds have proven to be an additional multi-trillion cubic foot reserve.

The Paradox basin is primarily an oil-producing province with associated and nonassociated gas. Significant potential gas resources are projected from a variety of stratigraphic and structural trap types similar to those presently discovered in Mesozoic and Permian sandstone; Pennsylvanian carbonate mounds, interfingering sandstone and fractured shale; Mississippian carbonates; and Devonian carbonate and sandstone. Several stratigraphic intervals and parts of the basin remain lightly explored. Gas/liquid ratios are expected to be higher in the deeper parts of the basin. The Snake River basin, Black Mesa basin and the Southern Basin and Range province are assigned only minor gas potential based on present information.

The estimate of Probable resources in the Greater Green River basin was decreased 1.1 Tcf as a result of successful development in the gigantic LaBarge Paleozoic low-Btu gas field. This shifted Probable resources to proved reserves. Possible resources in the Greater Green River Basin show a small change in depth distribution toward greater depths and a slight increase as a result of the combined effects of a new deep Cretaceous play in the eastern part of the basin and a downward revision of resources in Cretaceous strata of the Hanna basin. Speculative resources in the Greater Green River Basin were decreased by 3.3 Tcf as a result of a downward revision of resources in low-permeability Tertiary and Cretaceous strata of the Hanna basin as a result of information indicating poorer reservoir character than previously expected.

P-500, WILLISTON BASIN

This sedimentary basin covers more than 225,000 square miles in North Dakota, South Dakota, eastern Montana, southern Saskatchewan and southwestern Manitoba. It is bounded on the east by the Canadian Shield, on the southeast by the Sioux uplift, on the southwest by the Black Hills uplift and on the west by the Big Snowy uplift. Production occurs in all three states and both Canadian provinces. More than 16,000 feet of sedimentary rocks lie in the deepest portion of the basin, and, of these, 5,000 to 7,000 feet are Paleozoic sedimentary rocks, mostly carbonates and evaporites, and 6,000 feet are Mesozoic rocks, primarily clastics.

Gas production in this basin is primarily associated with oil. Exceptions to this are found in a handful of wells in the Ordovician and Cambro-Ordovician on and near the Nesson anticline and in the Cretaceous on the Cedar Creek anticline and on and near the Bowdoin dome.

The Probable resources are expected to be mostly associated gas, found within the boundaries of existing fields through field extensions. The Possible resources are expected to be mostly associated gas. Field size probably will be extremely variable, with most in the 1 to 3 Bcf range. The Speculative resources are expected to be primarily nonassociated gas found in fields from 3 to 100 Bcf.

Reservoir rocks. Production occurs in reservoir formations ranging in age from Cambrian to Cretaceous. These productive units are the Cretaceous Colorado Group and Montana Group; the Permian-Triassic Spearfish Formation; the Pennsylvanian Tyler Formation; the Mississippian Big Snowy Group and Madison Group; the Devonian-Mississippian Bakken Formation; Devonian carbonate rocks; the Silurian Interlake Formation; the Ordovician Stony Mountain, Red River and Winnipeg Formations; and the Cambrian Deadwood Formation. Cretaceous Dakota Group sandstones, as well as sandstones in the Jurassic Swift Formation, are potential reservoirs for natural gas.

Traps. Anticlines and faulted anticlines provide traps for all potential reservoirs. Stratigraphic trapping is also very important. Principal types of stratigraphic traps are porosity variations and truncations updip into impermeable units, such as evaporites. Next in importance are sandstone lenses and channels, found dominantly in the Big Snowy, Tyler and Lower Cretaceous units. Reefs, bioherms and buried topography form traps in the Red River, Interlake, Madison, and Devonian carbonate rocks. Combinations of these traps exist. Hydrodynamic trapping occurs in some anticlines.

Potential source rocks. Hydrocarbons in this basin were formed in numerous formations ranging in age from Cambrian to Paleocene. These formations include the Bakken, Red River, Winnipeg and Deadwood Formations, as well as the Paleocene Fort Union Formation; Upper Cretaceous Niobrara Formation; Lower Cretaceous Mowry Formation; Pennsylvanian Tyler Formation; Mississippian Heath and Lodgepole Formations; and Devonian Birdbear (Nisku) Formation.

Producing trends. The most noticeable structural feature in the province is the Cedar Creek anticline of southeastern Montana. This northwest-southeast-trending structure is over 100 miles long and contains up to 440 feet of productive section in lower Paleozoic carbonate rocks. Other major anticlines are the Bowdoin dome and Nesson and Billings anticlines.

P-500, WILLISTON BASIN
Generalized Stratigraphic Section

AGE	FORMATION	
	WEST	CENTRAL/EAST
Cenozoic		
Miocene	unnamed unit	unnamed unit
Oligocene	Brule Fm.	Brule Fm.
	Chadron Fm.	Chadron Fm.
Eocene		
Paleocene	Fort Union Gp.	Fort Union Gp.
Mesozoic		
Cretaceous		
Late	Hell Creek Fm.	Hell Creek Fm.
	Montana Gp.	Montana Gp.
	Fox Hills Fm.	Fox Hills Fm.
	Bearpaw Sh.	* Pierre Fm.
	Judith River Fm.	
	Claggett Fm.	
	* Eagle Fm.	
	Telegraph Creek Fm.	
	Colorado Gp.	Colorado Gp.
	† Niobrara Fm.	† Niobrara Fm.
	† Carlile Fm.	† Carlile Fm.
	† Greenhorn Fm.	† Greenhorn Fm.
	† Belle Fourche Fm.	† Belle Fourche Fm.
Early		Dakota Gp.
	† Mowry Fm.	† Mowry Fm.
	† Muddy Ss.	† Newcastle Fm.
	† Skull Creek Fm.	† Skull Creek Fm.
	† Dakota Fm.	† Inyan Kara Fm.
	† Kootenai Fm	
	† Lakota Fm.	
Jurassic	Morrison Fm.	
	† Swift Fm.	† Swift Fm.
	Rierdon Fm.	Rierdon Fm.
	† Piper Fm.	† Piper Fm.
	Nesson Fm.	
		Dunham Salt
Triassic		* Spearfish Fm.
Permo-Triassic	* Spearfish Fm.	
Paleozoic		
Permian		Pine Salt
	* Spearfish Fm.	* Spearfish Fm.
	Minnekahta Fm.	Minnekahta Fm.
	Opeche Fm.	Opeche Fm.
Penn.-Permian	Minnelusa Fm.	Broom Creek Fm.
Pennsylvanian	Amsden Fm.	Alaska Bench Mbr.
	* Tyler Fm.	* Tyler Fm.

* Currently producing
† Potentially productive

P-500, WILLISTON BASIN (continued)
Generalized Stratigraphic Section

AGE	FORMATION	
	WEST	CENTRAL/EAST
Paleozoic		
Mississippian	Big Snowy Gp.	Big Snowy Gp.
	* Heath Fm.	
	Otter Fm.	Otter Fm.
	* Kibbey Fm.	† Kibbey Fm.
	Madison Gp.	Madison Gp.
	* Charles Fm.	* Charles Fm.
	* Mission Canyon Fm.	* Mission Canyon Fm.
	† Lodgepole Fm.	† Lodgepole Fm.
Devonian-Miss.	* Bakken Fm.	* Bakken Fm.
Devonian	* Three Forks Fm.	* Three Forks Fm.
	* Birdbear ("Nisku") Fm.	* Birdbear ("Nisku") Fm.
	* Duperow Fm.	* Duperow Fm.
	† Souris River Fm.	† Souris River Fm.
	† Dawson Bay Fm.	† Dawson Bay Fm.
	Prairie Fm.	Prairie Fm.
	* Winnipegosis Fm.	* Winnipegosis Fm.
	Ashem Fm.	Ashem Fm.
Silurian	* Interlake Fm.	* Interlake Fm.
Ordovician-Silurian	* Stonewall Fm.	* Stonewall Fm.
Ordovician	* Stony Mt. Fm.	* Stony Mt. Fm.
	* Red River Fm.	* Red River Fm.
	* Winnipeg Fm.	* Winnipeg Fm.
Cambro-Ordovician	* Deadwood Fm.	* Deadwood Fm.

* Currently producing
† Potentially productive

P-510, POWDER RIVER BASIN

The Powder River basin is bounded on the east by the Black Hills, on the southeast by the Hartville uplift, on the south by the northwest end of the Laramie Range, on the west by the Casper arch and Big Horn Mountains, and on the north by the Miles City arch. This asymmetrical structural basin covers over 20,000 square miles. It is primarily an oil-producing basin, and natural gas represents a relatively minor portion of the basin's petroleum resources.

Gas found in all categories in the Powder River basin will be primarily associated gas. Very probably, the only nonassociated gas will be shallow coalbed methane. The Probable resources will come from field extensions, step-outs, etc., primarily in the deeper region of the basin. The Possible resources are expected to occur in field sizes of [illegible]00 Bcf and generally limited to the lower end of the range. Speculative resources may be found in the deeper synclinal area of the basin at 15,000 feet and greater in depth. Sizes may range from 20 to 200 Bcf.

Reservoir rocks. Potential reservoir rocks vary in age from Pennsylvanian to Cretaceous. Formations currently productive include the Upper Cretaceous Fox Hills Formation, Teapot Formation, Parkman Sandstone, Sussex Sandstone, Shannon Sandstone, Ash Creek Formation and Frontier Sandstone; the Lower Cretaceous Muddy-Dakota-Newcastle Formations, and Inyan Kara Group (Lakota Formation); the Jurassic Sundance Formation; and the Pennsylvanian Minnelusa-Tensleep Formations.

Traps. Anticlinal traps are common in the western portion of the basin. The central portion has buried topographic traps. The eastern portion is dominated by traps created by variations in the permeability of the reservoir rocks. Lenticular sandstones are found throughout the basin.

P-510, POWDER RIVER BASIN
Generalized Stratigraphic Section

AGE	FORMATION	
	WEST	EAST
Cenozoic		
Miocene	Lower Miocene rocks	
Oligocene	White River Fm.	
Eocene	Wagon Bed Fm.	
Paleocene	Fort Union Fm.	
Mesozoic		
Cretaceous		
Late	* Lance Fm.	* Lance Fm.
		* Fox Hills Fm.
	Meeteetse Fm.	Pierre Sh.
	* Mesaverde Fm.	
	* Cody Sh.	* Niobrara Fm.
		Carlile Fm.
	* Frontier Fm.	Greenhorn Fm.
		Bell Fourche Sh.
Early	* Mowry Sh.	* Mowry Sh.
	* Muddy Ss.-	* Newcastle Ss.
	Thermopolis Sh.	Skull Creek Sh.
	Cloverly Fm.	Inyan Kara Gp.
		* Fall River Fm.
		* Lakota Fm.
Jurassic	Morrison Fm.	Morrison Fm.
	* Sundance Fm.	* Sundance Fm.
	Gypsum Springs Fm.	Gypsum Springs Fm.
Triassic	Chugwater Fm.	Spearfish Fm.
Paleozoic		
Permian	Goose Egg-Phosphoria Fm.	Minnekahta Ls.
		Opeche Sh.
Pennsylvanian	* Tensleep Ss.	* Minnelusa Fm.
Mississippian	* Amsden Fm.	
	† Madison Ls.	Pahasapa Ls.
		Englewood Ls.
Devonian	Darby Fm.	
Ordovician	† Bighorn Dolo.	Whitewood Dolo.
Cambrian	Gallatin Ls.	Winnipeg Fm.
	Gros Ventre Fm.	† Deadwood Fm.
	Flathead Ss.	Flathead Ss.

* Currently producing
† Potentially productive

Potential source rocks. Organic-rich sedimentary rocks were deposited at various times during the history of the region. Potential source rocks range in age from Pennsylvanian to Paleocene. They include the Paleocene Fort Union Formation; Upper Cretaceous Lance, Lewis, Steele, Niobrara, Frontier and Greenhorn Formations; Lower Cretaceous Mowry and Skull Creek Shales; Jurassic Sundance Formation; Permian Phosphoria Formation; and Pennsylvanian Minnelusa Formation.

Potential for future exploration. The basin has good potential since large areas have not been explored. In explored areas, many potential reservoir rocks remain relatively untested. Many undiscovered stratigraphic traps are believed to exist.

Coalbed methane. The Powder River basin contains a large portion of the United States low-sulfur coals. It has been known for over thirty years that methane often vents from shallow water wells and coal exploration drill holes in the Powder River Coal Field. The gas occurs in sandstones and coalbeds at different stratigraphic levels in the Tongue River Member of the Paleocene Fort Union Formation.

Hundreds of shallow wells have been drilled in the past five years in the northern Powder River basin coal fields. The majority of the established gas production in the basin is from the shallow Fort Union sandstones. Methane from sandstone units, adjacent to coalbeds, has been produced at several locations in the basin, most notably at Chan, Oedekoven and Recluse fields. Attempts to establish economic production directly from coal beds have generally not been successful in the deep portion of the basin. Projects such as Dead Horse Creek and the Sasquatch Unit have experienced problems in dewatering the coalbeds. However, economic production has been established from coalbeds at Rawhide Butte field near Gillette, Wyoming.

Existing data suggests that a ton of coal in the Powder River basin might contain between 0 and 76 scf/ton methane with an average value of 19 scf/ton. It is estimated that 250 billion short tons of coal are prospective for in-place resource estimates of coalbed methane. This represents coalbeds that may occur above 1,500 feet around the margins of the basin. It is estimated that the possible in-place methane resource is between 2.9 and 9.5 Tcf, with the most likely recoverable estimate of 3.8 Tcf.

P-515, BIG HORN BASIN

This province covers approximately 11,000 square miles in northern Wyoming and southern Montana. It is primarily an oil province, and most gas occurs as associated/dissolved gas, although nonassociated gas is produced from Cretaceous formations as well as the Paleocene Fort Union Formation. The basin is bounded on the west by the Absaroka Range and the Beartooth Mountains, on the south by the Owl Creek Mountains, on the east by the Big Horn Mountains and on the north by the Nye-Bowler lineament. The basin is covered by Tertiary continental sedimentary rocks as much as 8,000 feet thick. Mesozoic sedimentary rocks are up to 9,800 feet thick. The Paleozoic section is only approximately 2,300 feet thick.

Reservoir rocks. Potential reservoir rocks range in age from Cambrian to Paleocene. The most prolific reservoirs are the Permian Phosphoria Formation (Embar Limestone Member) and the Pennsylvanian Tensleep Formation. Other reservoir formations are the Paleocene Fort Union Formation; Upper Cretaceous Lance Formation, Mesaverde Formation and Frontier Sandstone; Lower Cretaceous Muddy, Dakota, Lakota and Fuson Formations; Triassic Chugwater and Curtis Formations; Pennsylvanian Amsden Formation (Darwin Sandstone Member); Mississippian Madison Limestone; the Devonian Darby Formation; Ordovician Big Horn Dolomite; and Cambrian Flathead Sandstone.

Traps. The major traps are anticlines and faulted anticlines, often combined with changes in porosity and permeability of reservoir formations. Many reservoirs demonstrate tilted oil/water or gas/water contacts due to hydrodynamic flow of water through the permeable formations. Channel and lenticular sandstones occur as well as facies changes in the carbonate reservoir rocks.

Potential source rocks. Potential source rocks occur at several stratigraphic levels, including the Paleocene Fort Union Formation; Upper Cretaceous Lance, Mesaverde, Cody, Niobrara and Frontier Formations; Lower Cretaceous Mowry and Thermopolis Shales; Permian Phosphoria Formation; and in Upper Devonian rocks.

Future exploration. To the present time, exploration has concentrated on anticlinal structures in the basin, and the main target formations have been the Pennsylvanian-Permian units. Future targets include possible stratigraphic traps and the thick Mesozoic section, especially the various sandstones within the Mesaverde, Frontier and Dakota Formations.

P-520, WIND RIVER BASIN

This central Wyoming basin is bounded on the west and southwest by the Wind River Mountains, on the south by the Granite Mountains, on the north by the Owl Creek Mountains and the Washakie Range and on the east by the Casper arch. The basin covers approximately 8,500 square miles. Approximately three-fourths of the basin contains more than 20,000 feet of Paleocene-Eocene sedimentary rocks, and up to 30,000 feet of total sedimentary section occurs in the deeper portions of the basin. The basin was emergent during much of Paleozoic time; thus very little Paleozoic section exists, and there is nearly four times as much Mesozoic section as Paleozoic.

Structural features include a series of north-northwest-trending folds along the southern flank of the basin. Along the northern flank, rocks of the Owl Creek Mountains have been thrust southward over younger sedimentary rocks of the basin, and on the east the Casper arch is thrust west over sedimentary rocks.

Natural gas in the Wind River basin occurs as both associated/dissolved gas and as nonassociated gas. Most of the gas resource is nonassociated. Many fields produce from multiple reservoirs. A multi-billion cubic foot accumulation in the Mississippian Madison Limestone has been discovered by a well on the Madden anticline below 20,000 feet.

Reservoir rocks. The major developed reservoir formation in the basin is the Pennsylvanian Tensleep Formation, but additional formations produce gas and/or oil in the basin, including the Tertiary Wind River and Fort Union Formations; Upper Cretaceous Lance, Mesaverde, Cody and Frontier Formations; Lower Cretaceous Muddy, Dakota, Cloverly-Lakota Formations; Jurassic Morrison and Sundance-"Curtis" Formations; Triassic Nugget and Crow Mountain Formations; Permian Phosphoria Formation (Embar Limestone Member) and Mississippian Madison limestone. Many of the Tertiary and Upper Cretaceous reservoirs fall in the "tight" classification.

Traps. Anticlines and faulted anticlines form traps in all stratigraphic intervals. Sandstone channels and lenses are common. Porosity and permeability changes and pinch outs are also abundant in all intervals.

Potential source rocks. Potential source rocks range in age from Permian to Tertiary. They include the Tertiary Fort Union-Waltman Formations; Upper Cretaceous Lance, Mesaverde, Cody, Niobrara and Frontier Formations; Lower Cretaceous Mowry and Thermopolis Shales; and Permian Phosphoria Formation.

Future exploration. The Wind River basin is in an intermediate stage of exploration. New drilling and completion technology may significantly increase the reserves of the basin. The new fluid drilling systems and external casing packers are attempting to protect interstitial reservoir clays from fluid damage. This technology would exploit potential reserves of discontinuous lenticular sands of the Cretaceous Fort Union, Lance, Meeteetse and Mesaverde formations.

P-515, BIG HORN BASIN
Generalized Stratigraphic Section

AGE		FORMATION
Cenozoic		
Eocene		Wapiti-Aycross Fms.
		Tatman-Willwood Fms.
Paleocene	*	Fort Union Fm.
Mesozoic		
Cretaceous		
Late	*	Lance Fm.
	*	Meeteetse Ss.-Lewis Sh.
		Mesaverde Fm-Teapot Ss. Mbr.
		Mesa Verde Fm.
		Cody Sh.
Early	*	Frontier Fm.
		Mowry Sh.
	*	Thermopolis-Muddy Ss. Mbr.
		Thermopolis Sh.
	*	Cloverly Fm.
Jurassic		Morrison Fm.
	*	Sundance Fm.
		Gypsum Spring Fm.
		Nugget Ss.
Triassic		Chugwater Gp.
		Popo Agie Fm.
		Crow Mountain Ss.
		Alcova Ls.
		Red Peak Fm.
Paleozoic		
Permian	*	Dinwoody-Phosphoria (Goose Egg Fm.)
Pennsylvanian	*	Tensleep Ss.
	*	Amsden Fm.
Mississippian	*	Madison Ls.
Devonian	*	Darby Fm.
Silurian		
Ordovician		Bighorn Dolo.
Cambrian		Gallatin Ls.
		Gros Ventre Fm.
	*	Flathead Ss.

* Currently producing
† Potentially productive

P-520, WIND RIVER BASIN
Generalized Stratigraphic Section

AGE		FORMATION
Cenozoic		
Miocene		Split Rock Fm.
Oligocene		White River Fm.
Eocene		Wagon Bed-Teepee-Aycross Fms.
	*	Wind River Fm.
		Indian Meadows Fm.
Paleocene-Eocene	*	Fort Union Fm.
Mesozoic		
Cretaceous		
Late	*	Lance Fm.
	†	Meeteetse Fm.-Lewis Sh.
	*	Mesaverde-Teapot Ss. Mbr.
		Mesaverde-Parkman Ss. Mbr.
	*	Cody-Steele-Niobrara Fm.
	*	Frontier Fm.
Early		Mowry Sh.
	*	Muddy Ss. Mbr., Thermopolis Sh.
		Thermopolis Sh.
	*	Cloverly Fm.
Jurassic	*	Morrison Fm.
	*	Sundance Fm.
		Gypsum Spring Fm.
	*	Nugget Ss.
Triassic		Chugwater Gp.
		Popo Agie Fm.
	*	Crow Mountain Fm.
		Alcova Ls.
		Red Peak Fm.
		Dinwoody Fm.
Paleozoic		
Permian	*	Phosphoria Fm.
Pennsylvanian	*	Tensleep Fm.
	†	Amsden Fm.
Mississippian	*	Madison Ls.
Devonian		Darby Fm.
Ordovician		Bighorn Dolo.
Cambrian		Gallatin Ls.
		Gros Ventre Fm.
		Flathead Ss.

* Currently producing
† Potentially productive

P-530, GREATER GREEN RIVER BASIN, HANNA AND LARAMIE BASINS

The Greater Green River basin extends over parts of southwestern Wyoming, northeastern Utah and northwestern Colorado. The province includes several smaller basins in addition to the Green River basin proper: Red Desert basin, Washakie basin, Sand Wash basin, Hanna basin, Kindt basin, Shirley basin and Laramie basin. Approximately 27,000 square miles of prospective sedimentary basins are included in this province, which is bounded on the west by the Overthrust belt, on the north by the Wind River and Granite Mountains, on the east by the Laramie Range and on the south by the Uinta Mountains and the Axial Basin anticline. The Green River basin proper contains more than 20,000 feet of Paleocene-Eocene continental sedimentary rocks. The aggregate sedimentary section is greater than 30,000 feet thick.

Although about 11,000 wells have been drilled in the province, large areas are still sparsely tested, and vast areas are virtually untested below the shallowest of several prospective stratigraphic horizons. Throughout much of the basin, the Frontier, Dakota and Paleozoic Formations are at an early stage of exploration. Even the lower part of the Mesaverde Group is largely undrilled throughout much of the Green River, Red Desert and Washakie basins.

The Probable resources are expected to be found in field and trend extensions dominated by the LaBarge platform, Moxa arch and Wamsutter arch/Washakie basin complexes. Methane from low-Btu gas entrapped in Paleozoic reservoirs of the LaBarge Platform comprises much of the Probable and Possible resources. The Possible resources are expected to be found in fields ranging in size from 2 to 1,000+ Bcf, with many of them in the 5 to 50 Bcf range. The Speculative resources are expected to be found in fields ranging in size from 2 to 1,000 Bcf, with the most likely size being between 10 to 200 Bcf.

Reservoir rocks. Potential reservoir rocks range in age from Cambrian to Eocene. The major producing formations are sandstones of the Tertiary Wasatch and Fort Union Formations; Upper Cretaceous Lewis, Mesaverde Group (including the Almond), Frontier Formation; Lower Cretaceous Dakota Group; Juro-Triassic Nugget Sandstone and Mississippian Madison Limestone. Other reservoirs include the Upper Cretaceous Lance-Fox Hills, Niobrara Formation, the Baxter and Steele Shales; Muddy Sandstone, Jurassic Morrison and Sundance, Permian Phosphoria Formation; Permo-Pennsylvanian Weber-Tensleep, the Pennsylvanian Amsden and Morgan Formations and Cambrian Flathead Sandstone. Many potential Cretaceous reservoir rocks have low permeability.

Traps. Anticlines and faulted anticlines provide traps for reservoirs of all ages. Together with the structural traps, sandstone pinch outs and permeability changes form the major trapping mechanisms. Combination sandstone pinch out-fault traps are productive in some areas.

Potential source rocks. Potential source rocks range in age from Mississippian to Eocene. They include the Eocene Wasatch and Green River Formations; Paleocene Fort Union Formation; Upper Cretaceous Lance, Lewis, Mesaverde, Baxter-Niobrara and Greenhorn Formations; Lower Cretaceous Mowry-Aspen and Thermopolis Shales; Jurassic shale; Permian Phosphoria Formation; and Mississippian shale and carbonates. Paleocene and Upper Cretaceous coalbeds are major sources of gas and condensate in the deep parts of the basins.

Future exploration. Although the Greater Green River basin is a major natural gas province, it is still lightly explored. Throughout an area of 13,000 square miles, the Cretaceous Frontier and Dakota Sandstones have been penetrated in only one percent of the sections. Thrusting of Precambrian rocks over the northern and southern margins of the basins and fractured reservoirs along lineament trends could prove to be of exploration interest. Future exploration will require adequate economic incentives, presently lacking, in order to justify pursuit of subtle stratigraphic traps in deep, low-perme-

ability reservoirs. Most of the deep gas will be produced from depths of less than 20,000 feet. Exploitation of methane contained in low-Btu gas of the LaBarge/Moxa arch Paleozoic reservoirs is dependent upon the economics of tertiary recovery of oil using the major component of the gas—carbon dioxide. The LaBarge Paleozoic reservoir is also a major producer of helium and sulfur.

Coalbed methane. The Greater Green River Coal Region is a complex system of basins extending over 21,000 square miles in southwestern Wyoming and northwestern Colorado. The Greater Green River Coal Region comprises five distinct, structurally separate basins: Green River, Great Divide, Washakie and Sand Wash basins and the Rock Springs Uplift. Up to 40,000 feet of Paleozoic to Quaternary sedimentary rocks occur in the basins. Coal seams are found in many formations within the basin but are thickest and laterally most extensive in the Cretaceous Mesaverde Group and Paleocene Fort Union formation. Total coal thickness in these formations can exceed 200 feet from as many as 30 coal seams. Gas contents range from approximately 20 scf/ton in subbituminous Tertiary-age coal to over 500 cf/ton in high-volatile A bituminous coal from the Mesaverde Group. Coalbed methane exploration has intensified since 1988, with more than 50 new wells drilled by the end of 1990. Most of the activity has been focused on the Rock Springs Uplift and the Sand Wash basin. Nevertheless, the Greater Green River Coal Region remains a frontier coalbed methane province.

P-535, DENVER BASIN, CHADRON ARCH AND LAS ANIMAS ARCH

This province covers over 95,000 square miles and includes three widely different geological features: the Denver basin, the northern portion of the Las Animas arch and the Chadron-Cambridge arches complex. The Denver basin is a north-south asymmetrical tectonic basin in eastern Colorado, southwestern Nebraska and southeastern Wyoming. It is bounded on the southeast by the Las Animas arch, on the northeast and east by the Chadron-Cambridge arches, on the north and northwest by the Hartville uplift, on the west by the Laramie Mountains and the Front Range and on the south by the Apishapa uplift. More than 13,000 feet of sedimentary rocks, mostly of Cretaceous age, lie in the deepest portion of the basin, below the city of Denver. The rocks thin to less than 6,000 feet on the gently dipping eastern flank of the basin. Both associated and nonassociated gas is found in all parts of the basin, while dry gas is limited to the shallow eastern side. This basin also includes the Canon City embayment, which contains the second oldest oil field in the United States, discovered in 1862.

The Las Animas arch is a Late Cretaceous-age uplift that extends northeasterly from southeast Colorado through northwest Kansas into south central Nebraska where it terminates in the Cambridge arch which runs perpendicular to the Las Animas arch. Depth to the Precambrian basement is about 6,000 feet along the Las Animas arch and ranges from more than 5,000 feet to zero along the Chadron-Cambridge arches. The latter arches form the northwest extension of the Central Kansas uplift, and they terminate to the north in the Black Hills uplift.

The Denver basin accounts for over 95 percent of the gas that has been produced from this province. The amount produced from the Las Animas arch is slightly less than 4 percent. Less than one percent has been produced from the Chadron arch, all of it in South Dakota.

Probable resources are expected to be found in field extensions of Cretaceous and Pennsylvanian sedimentary rocks. In order of estimated magnitude of future potential, starting with the largest, they are: the "J" Sandstone, Niobrara chalk, Codell, Plainview-Lytle, Terry and Hygiene, Morrow, Leo, and "D" sandstones. Possible resources are expected to be discovered in the same rock units. Field sizes should range from 0.5 to 500 Bcf with most of them averaging 2 to 50 Bcf. Production of Possible resources should be concentrated within the deep, axial section of the Denver basin, the southeast Colorado segment of the Las Animas arch and the South Dakota portion of the Chadron arch. Shallower pool, and, to a lesser extent, deeper pool discoveries will be significant. Speculative resources will most likely come from presently unproductive sandstone, siltstone and carbonates of the Lower and Upper Cretaceous and Upper Paleozoic systems. Many of these reservoirs will be shaly and have low permeability.

P-530, GREATER GREEN RIVER BASIN, HANNA AND LARAMIE BASINS
Generalized Stratigraphic Section

AGE	FORMATION WEST	FORMATION CENTRAL	FORMATION EAST
Cenozoic			
Miocene	Miocene rocks	Miocene rocks	Miocene rocks
Oligocene	conglomerate	Bishop Cgl.	† White River Fm.
Eocene	† Bridger Fm.		Wagon Bed Fm.
	† Green River Fm.		Wind River Fm.
Paleocene	Hoback Fm.	* Fort Union Fm.	* Hanna Fm.
			† Ferris Fm.
Mesozoic			
Cretaceous		† Lance Fm.	* Medicine Bow Fm.
Late		Fox Hills Ss.	† Fox Hills Ss.
		Lewis Sh.	* Lewis Sh.
		* Almond Fm.	Mesaverde Gp.
		* Ericson Fm.	
		* Rock Springs Fm.	
	Adaville Fm.	* Blair Fm.	
	* Hilliard Fm.	* Baxter Sh.	* Steele Sh.
			* Niobrara Fm.
	* Frontier Fm.	* Frontier Fm.	* Frontier Fm.
Early	* Aspen Sh.	* Mowry Sh.	* Mowry Sh.
	Bear River Fm.	* Muddy Ss. Mbr.	* Muddy Ss. Mbr.
		Thermopolis Sh.	
	* Cloverly Fm.	* Cloverly Fm.	* Cloverly Fm.
Jurassic	* Morrison Fm.	* Morrison Fm.	* Morrison Fm.
	Curtis Fm.	Curtis Fm.	* Sundance Fm.
	Entrada Ss.	Entrada Ss.	
	Twin Creek Ls.	Carmel Fm.	
	* Nugget Ss.	* Nugget Ss.	* Nugget Ss.
Triassic	Ankareh Fm.	Ankareh Fm.	Jelm Fm.
	Thaynes Fm.	Red Peak-Woodside Fm.	Chugwater Fm.
	Woodside Fm.		
	Dinwoody Fm.	Dinwoody Fm.	
Paleozoic			
Permian	* Phosphoria Fm.	* Phosphoria Fm.	† Goose Egg Fm.
Pennsylvanian	* Weber Ss.	Weber-Tensleep Ss.	Casper Fm.
Miss.-Penn.	Amsden Fm.	* Morgan Fm.	
		Round Valley Fm.	
Mississippian	* Madison Ls.	* Madison Ls.	* Madison Ls.
Devonian	Darby Fm.	Darby Fm.	
Silurian	Laketown Dolo.		
Ordovician	Bighorn Dolo.	Bighorn Dolo.	
Cambrian	Gallatin Ls.	Buck Springs Fm.	Cambrian rocks
	Gros Ventre Fm.		
	* Flathead Ss.	* Flathead Ss.	

* Currently producing
† Potentially productive

Reservoir rocks. The only dry gas in this province comes from the tight reservoirs of the Niobrara Formation chalks along the eastern side of the Denver basin and from adjacent parts of the Las Animas and Cambridge arches. This "tight gas" accounts for about 10-12 percent of the province's recent gas production. The most significant reservoir rock in the basin is the Lower Cretaceous "J" Sandstone of the Dakota Group, also a tight reservoir in the Wattenberg area. The nonassociated, wet gas produced from the "J" Sandstone in the Denver basin accounted for about 35 percent of the recent production. In the Wattenberg area, large volumes of gas are also produced from deeper and shallower pool sandstone and fractured marl over a 4,000 foot vertical interval. In this western and deepest part of the Denver basin, important reservoirs are located in the Upper Cretaceous strata. They include the shelf and offshore marine sandstone complexes of the Terry, Hygiene and Codell Sandstones and the fractured marl and chalk of the Niobrara Formation. These reservoirs account for approximately 40 percent of the gas produced. Over 10 percent of the province's gas came from numerous, rather small (about 2 to 5 Bcf average size), "J" and "D" Sandstone fields in northeast Colorado, Nebraska and Wyoming. These reservoirs have porosities that approach 30 percent on the shallow east flank and become progressively less porous toward the deeper west. Minor gas reservoirs are found in the Upper Cretaceous Parkman Sandstones and Greenhorn Limestones, the Lower Cretaceous Plainview-Lytle sandstones and the Permian Lyons Sandstone.

Very few wells in the Denver basin have been drilled below the Lower Cretaceous section. A recent play, centered in southwest Nebraska and northeast Colorado, is aimed at testing upper Paleozoic rocks. Some excellent oil reservoirs have been found in Permian- and Pennsylvanian-age clastics and carbonates. A little associated gas has also been discovered. Other potential reservoirs exist in tight, fractured marl, siltstone and shale of Cretaceous age and in the Mississippian, Devonian, Ordovician and Cambrian strata.

The principal gas reservoir on the Las Animas arch is the Lower Pennsylvanian Morrow sandstone, which contributed less than 4 percent of the gas produced in the province recently. Morrow gas is often rich in helium and low in Btu content. Some minor gas is associated with the multiple oil reservoirs, dominantly carbonates, ranging from Mississippian through Permian in age.

Along the Chadron-Cambridge arches, very little associated gas comes from the many oil fields producing within Pennsylvanian carbonates and clastics. One exception is the Leo sandstones (Minnelusa equivalent) of Pennsylvanian age from which associated gas is produced in South Dakota. Several undeveloped accumulations of shallow gas have been found in the Niobrara Formation chalks and in the Dakota Group sandstones.

Traps. In the Denver basin, the major traps are formed by facies changes, but important accumulations are also derived from structures, structural-stratigraphic features and fractures. Marine shales form the principal seals. Anticlines and faulted structural traps are confined to the mountain fronts in the west, and to the east central and east portions of the basin. The eastern, shallow Niobrara Formation chalks produce gas from complex, highly faulted structures capped by a 10- to 30-foot-thick bentonite seal. Fractures have enhanced production from the low-permeability rocks in the deep Denver basin and from the tight, shallow chalks to the east.

Basement tectonic movements formed the structures, caused the fracturing and controlled the depositional patterns in the sedimentary rocks. The Cretaceous-age sandstones were deposited in a broad variety of clastic environments ranging from fluvial valleys, coastal and deltaic to offshore marine.

Morrow sandstones were deposited in valley-fill, estuarine and marine-shelf environments in the Las Animas arch area. The Leo sandstones were part of a coastal eolian/sabkha depositional system. Carbonate biohermal and structural traps are prevalent in the Permian- through Mississippian-age fields along the Las Animas and Chadron arches.

Potential source rocks. Cretaceous marine shales are the dominant source rocks for the region. The major ones are found in the Niobrara Formation and the Mowry and Huntsman Shales. Also contributing hydrocarbons are the Carlile, Granerous and Skull Creek Shales and the Greenhorn Limestone. These source beds are mature only in the deepest portion of the Denver basin, generally below 6,000 feet. Regional igneous thermal activity related to the Colorado Mineral Belt of the Transcontinental Arch also contributed to source rock maturity. Some gas has migrated updip to fields over 100 miles to the east from the downdip mature areas. Vertical migra-

P-535, DENVER BASIN, CHADRON ARCH AND LAS ANIMAS ARCH
Generalized Stratigraphic Section

AGE	FORMATION		
	DENVER BASIN		LAS ANIMAS ARCH
	WEST	EAST	
Cenozoic			
Miocene	Ogalalla Gp.	Ogalalla Gp.	
	Arikaree Gp.	Arikaree Gp.	
Oligocene	White River Gp.	White River Gp.	
Eocene-Paleo.	† Denver Fm.-	Green Mountain Cgl.-	
	Green Mountain Cgl.	Dawson Fm.	
Mesozoic			
Cretaceous			
Late	Arapahoe Fm.	Arapahoe Fm.	
	† Laramie Fm.	Laramie Fm.	
	Fox Hills Fm.	Fox Hills Fm.	
	* Pierre Sh.	* Pierre Sh.	Pierre Sh.
	† Richard Ss. Mbr.-("Teapot")		
	* Larimer-Rocky Ridge Ss. Mbrs.-("Parkman")		
	* Terry Ss. Mbr.-("Sussex")		
	* Hygiene Ss. Mbr.-("Shannon")		
	Niobrara Gp.	Niobrara Gp.	Niobrara Fm.
	* Smoky Hill Sh. Mbr.	* Smoky Hill Sh. Mbr.	* Smoky Hill Sh. Mbr.
	* Ft. Hays Ls. Mbr.-(Timpas)	Ft. Hays Ls. Mbr.	
	Benton Gp.	Benton Gp.	
	† Carlile Sh.	† Carlile Sh.	Carlile Fm.
	* Codell Ss. Mbr.	* Codell Ss. Mbr.	* Codell Ss. Mbr.
	* Greenhorn Fm.	Greenhorn Fm.	Greenhorn Ls.
	† Graneros Sh.	† Graneros Sh.	Graneros Sh.
	† Mowry Sh.		
Early	* Dakota Gp.	* Dakota Gp.	Dakota Gp.
	* "D" Ss. Mbr.	* "D" Ss. Mbr.	Purgatoire Fm.-
	* "J" Ss. Mbr.	* "J" Ss. Mbr.	Cheyenne Ss.
	* Plainview-Lytle Fms.		
Jurassic	† Morrison Fm.	Morrison Fm.	Morrison Fm.
	Ralston Creek Fm.	Ralston Creek Fm.	Ralston Creek Fm.
	† Entrada Ss. (Sundance)		Entrada Ss.
	Jelm Fm.		Dockum Gp.
Triassic	Lykins Fm. (upper)		

* Currently producing
† Potentially productive

P-535, DENVER BASIN, CHADRON ARCH AND LAS ANIMAS ARCH (continued)
Generalized Stratigraphic Section

AGE	FORMATION		
	DENVER BASIN		LAS ANIMAS ARCH
	WEST	EAST	
Paleozoic			
Permian		† Forelle Ls.	Day Creek Dolo.
	Lykins Fm. (lower)		Whitehorse Fm.
	* Lyons Fm.-Satanka Sh.	Nippewalla Gp.	Nippewalla Gp.
		Wellington Gp.	Sumner Gp.
	Ingelside Fm.	* Wolfcamp Fm.	Chase Gp.
	† Fountain Fm.		Council Grove Gp.
			Admire Gp.
Pennsylvanian	† Fountain Fm.	* Virgil Age	Wabaunsee Fm.
			* Shawnee Fm.
			* Douglas Fm.
		* Missouri Age	* Lansing Fm.
		* "Leo" Ss.	* Kansas City Fm.
		* Des Moines Age	Pleasanton Gp.
			* Marmaton Fm.
			* Cherokee Fm.
		† Atoka Fm.	† Atoka Fm.
		† Morrow Fm.	* Morrow Fm.
Mississippian			
	Beulah Ls.		* Ste. Genevieve Fm.
	Hardscrabble Ls.	St. Louis Ls.	* St. Louis Fm.
	Leadville Ls.	† Salem Fm.	* Spergen Fm.
		Warsaw Fm.	* Warsaw Fm.
		† Osage Gp.	* "Osage" Gp.
			Gilmore City Ls.
		† Kinderhook Gp.	† Kinderhook Sh.- Misener Ss.
Ordovician			Viola Fm.
	† Fremont Ls.		Simpson Gp.
	† Harding Ss.		
	† Manitou Ls.	† Arbuckle Gp.	† Arbuckle Gp.
Cambrian		† Reagan Ss.	Reagan Ss.
	† Peerless Fm.		
	Sawatch Quartzite		

* Currently producing
† Potentially productive

tion of over 2,500 feet has also been noted. The shallow eastern Niobrara formation gas has a biogenetic source rather than a thermal one. Permian and Pennsylvanian cyclic black marine shales constitute the source beds for the Las Animas and Chadron arches and for the Paleozoic production in the Denver basin.

P-540, UINTA AND PICEANCE BASINS, PARK BASINS AND EAGLE BASIN

This province contains six basins: Uinta, Piceance, Eagle, North Park, Middle Park and South Park. Hydrocarbons produced in the region are oil, associated/dissolved gas and nonassociated gas. Large amounts of both oil and gas are produced in the Uinta basin. The Piceance basin is predominantly a gas province and may have the potential to be a nearly continuous gas field similar to that which occurs in the San Juan basin; however, recovery per well is expected to be small.

The Uinta basin is the largest and most highly productive portion of the province. It is bounded on the north by the Uinta Mountains, on the west by the Wasatch Range, on the south by the San Rafael swell and Uncompahgre uplift, and on the east by the Douglas Creek arch. The axis of this asymmetric, east-west-trending basin lies in the northern portion of the basin. Sedimentary rocks are more than 30,000 feet thick in this region; more than 11,000 feet of these are Tertiary continental and lacustrine deposits. Major downwarping of the basin occurred during the Late Cretaceous and Eocene.

The Piceance basin is the second largest and second most productive portion of the province. It is bounded on the west by the Douglas Creek arch, on the north by the Axial Basin anticline, on the east by the White River uplift and on the southwest by the Uncompahgre uplift. Up to 27,000 feet of sedimentary rocks were deposited in the deepest portion of the basin. Most fields in this region produce from more than one interval; some have up to six reservoirs. Rangely field, which lies on the Douglas Creek arch, is the only giant oil and gas field in Colorado.

Eagle and North Park basins continue to be areas of exploration interest. Small amounts of both oil and gas are produced in these basins. South Park and Middle Park contain no production at this time. South Park has some potential for production. Middle Park has very little potential.

Cumulative gas production from this province exceeds 3 Tcf. Approximately 75 percent of the production comes from reservoirs ranging from Early Cretaceous to early Tertiary in age. In the Uinta and Piceance basins, approximately 15-20 percent of the potentially productive area has been adequately tested through the Cretaceous section. Possible Cretaceous objectives remain virtually undrilled in the deeper portions of the Uinta basin, while large tracts underlain by potential Tertiary and Cretaceous reservoirs remain untested in the central Piceance basin. Drilling activity in the near future will focus on infill and extension or exploitation drilling. Some exploratory drilling will be completed and the majority of this will most likely be within existing fields. The slight reduction in the probable minimum category is based on the possibility that infill drilling will not recover any new, unique resources. All other probable and possible categories are increased as a result of the infill and extension drilling activity. The increases in the most likely categories partially reflect the possibility that the infill drilling is exploiting both unique and already developed resources. Whereas, the increases in the maximum categories reflect the possibility that all of the infill resources are unique.

Probable resources are expected to be found mostly in field extensions and new pool discoveries within existing fields. Possible resources are to be found in fields ranging in size from 1 to 200 Bcf, with most fields falling within the 2 to 20 Bcf range. The size of fields for Speculative resources should range from 10 to 1,000 Bcf, with an average field size of around 100 Bcf.

Reservoir rocks. The Eocene Green River and Wasatch Formations are the primary reservoirs in the Uinta basin as well as being important units in the Piceance basin. In the Park basins some production is from the Paleocene Coalmont Formation. Cretaceous reservoirs in this province are the Mesaverde, Mancos, Frontier, Codell, Dakota, Muddy and Lakota sandstones. Some fields produce from fractured Pierre and Niobrara intervals. Jurassic sandstone reservoirs are the Morrison

and Entrada Formations. Productive Paleozoic units are the Permian Phosphoria Formation, Pennsylvanian-Permian Weber Sandstone, and Pennsylvanian Minturn Formation.

Traps. Stratigraphic traps are very important in this province, including deltaic lenses, channel and bar sands, permeability pinch outs and asphalt seals. Present production from stratigraphic traps is confined to Cretaceous and Paleocene rocks. Traditional structural traps in the province are fault traps, anticlines and faulted anticlines, which affect all stratigraphic intervals. Unconformity surfaces form traps in the Weber and Phosphoria Formations.

Potential source rocks. Source rocks in the Uinta, Piceance and Eagle basins range in age from Mississippian to Eocene. All are mature in certain areas. These source units are the Eocene Wasatch and Green River formations; Upper Cretaceous Mesaverde Group and Mancos Shale; Pennsylvanian Phosphoria and Belden shales, Mississippian Manning Canyon Shale and Deseret Limestone. Possible source rocks for the Park basins are the Cretaceous Niobrara, Greenhorn, Mowry and Thermopolis formations.

Coalbed methane. Coalbed methane in-place resource estimates for the Piceance basin range from 30-110 Tcf. The most likely in-place estimates range from 60 to 77 Tcf. There are approximately 100 coalbed methane completions in the Piceance basin. They are primarily drilled on 320-acre spacing units. Most of these completions are new with little production history. (Curtailments are also affecting production history.) However, industry sources estimate that average recoverable reserves will range from 500 to 1,000+ MMcf per location and the most likely value being 700 MMcf per location. Based on all the information, the combined probable and possible recoverable estimates for the Piceance basin range from 615 Bcf to 29.8 Tcf. The most likely combined recoverable estimate is 4.7 Tcf. (There is no speculative resource estimate based on the Potential Gas Committee's definition.) These estimates will continue to be redefined as more wells are drilled, and more production history is obtained.

P-545, SAN JUAN MOUNTAINS, SAN LUIS BASIN, LAS VEGAS-RATON BASIN, SIERRA GRANDE UPLIFT

This region of southern Colorado and northeastern New Mexico contains two structural basins, two structural arches and two mountain ranges. Present production is restricted to minor amounts of nonassociated gas scattered through the province. Most of the production is located in the northern part of the Las Vegas-Raton basin. Two fields are located on the Apishapa uplift and one field lies at the southern nose of the Uncompahgre Mountains in Ouray County, Colorado. The Las Vegas-Raton basin contains over 7,200 feet of sedimentary rocks ranging in age from Devonian to Holocene. The San Luis basin is considered a northern extension of the Rio Grande Rift and is cross-cut by numerous fault blocks. Total sediment thickness, which may exceed 20,000 feet, varies greatly over these blocks. Much of the San Luis basin and the Sierra Grande arch are covered with volcanics. Carbon dioxide is produced from Jurassic sandstones and Pennsylvanian-Permian arkoses in Harding County, New Mexico. Helium, nitrogen and carbon dioxide are produced from the Permian at the Model Dome field on the Apishapa uplift.

Reservoir rocks. Potential reservoir rocks range in age from Pennsylvanian to Paleocene. They include the Cretaceous-Paleocene Raton Formation; Upper Cretaceous Vermejo Formation, Trinidad Sandstone, fractured Niobrara Formation, Codell Sandstone Dakota equivalents; Jurassic Entrada Sandstone; Permian Glorieta Sandstone; Pennsylvanian-Permian Sangre de Cristo Formation; and Pennsylvanian Madera Limestone.

Traps. Stratigraphic traps may be found in most intervals. These include sandstone lenses and porosity pinchouts. Structural traps include anticlines, faulted anticlines and reverse faults. Combinations of these traps may exist.

P-540, UINTA-PICEANCE BASINS, PARK BASINS AND EAGLE BASIN
Generalized Stratigraphic Section

AGE	FORMATION		
	UINTA BASIN	PICEANCE BASIN	EAGLE, ETC. BASINS
Cenozoic			
Eocene	Duchesne R. Fm.	Green River Fm.	
	* Uinta Fm.		
	* Green River Fm.		
Paleocene	North Horn-	* Wasatch Fm.	
	* Wasatch Fm.	Ohio Creek Fm.	
Mesozoic			
Cretaceous	* Mesaverde Gp.	* Mesaverde Gp.	
	Mancos Sh.	Mancos Sh.	Mancos Sh.
	* Frontier Ss. Mbr.	* Frontier Fm.	* Dakota Ss.
	Mowry Sh.	Mowry Sh.	
	* Dakota Ss.	* Dakota Gp.	Burro Canyon Fm.
	* Cedar Mountain Fm.	Burro Canyon Fm.	
Jurassic	* Morrison Fm.	Morrison Fm. &	* Morrison Fm.
		Salt Wash Mbr.	
	Curtis Fm.	† Curtis Fm.	
	* Entrada Ss.	† Entrada Ss.	† Entrada Ss.
	Carmel Fm.		
	Nugget Ss.		
		Navajo Ss.	
Triassic	Chinle Fm.	Chinle Fm.	Chinle Fm.
	Gartra Grit Fm.	† Shinarump Ss. Mbr.	
Paleozoic			
Permian	Moenkopi Fm.	Moenkopi Fm.	
	Park City Fm.		* State Bridge Fm.
		Phosphoria Fm.	
	* Upper Weber Ss.	* Upper Weber Ss.	Maroon Fm.
			Eagle Valley Fm.
Pennsylvanian	* Lower Weber Ss.	* Lower Weber Ss.	
	Morgan Fm.	* Minturn Fm.	Minturn-Gothic Fm.
	Round Valley Ls.	† Belden-Maroon Fm.	† Belden Fm.
Mississippian	Doughnut Fm.		
	* Humbug Fm.		
	Deseret Ls.	† Leadville Ls.	† Leadville Ls.
	Gardison-Madison Ls.		
Devonian		Chaffee Fm.	Chaffee Gp.
			Gilman Ss.
			Dyer Dolo.
			Parting Fm.
Ordovician			Fremont Ls.
			Harding Ss.
		Manitou Fm.	Manitou Ls.
Cambrian	Lodore Ss.	Dotsero Fm.	Peerless Fm.
			Sawatch Quartzite
	Maxfield Ls.	Sawatch Ss.	
	Ophir Fm.		
	Tintic Quartzite		

* Currently producing
† Potentially productive

Potential source rocks. The most likely source rocks in the province are the Raton and Vermejo Formations and Colorado Group. Paleozoic carbonate rocks may also be source beds in parts of the province.

Coalbed methane. A resource of 8.0 to 18.4 Tcf of in-place coalbed methane is estimated for the coals of the Raton basin. No estimate of the recoverable resource has been made.

P-550, PARADOX BASIN

This province covers most of southeastern Utah and part of southwestern Colorado and contains three major producing regions: the Paradox basin, the Uncompahgre uplift and the San Rafael Swell. Carbon dioxide and helium are also produced in the province. The asymmetrical Paradox basin is about 200 miles long and 100 miles wide and contains more than 24,000 feet of sedimentary rocks ranging in age from Proterozoic to Cenozoic. The basin is bounded on the west and southwest by the San Rafael Swell, on the west by the Circle Cliffs, on the south by the Tyende Saddle and Defiance uplift, on the southeast by the Four Corners Platform, and on the east and northeast by the San Juan Mountains and Uncompahgre uplift. Major downwarping of the basin occurred during the Pennsylvanian and Permian Periods, with the deepest portion of the basin forming directly adjacent to the Uncompahgre uplift.

Reservoir rocks. Major oil and gas production in the Paradox basin is from carbonates in the Pennsylvanian Hermosa Group and the Mississippian Leadville Formation. Biohermal carbonate mounds in the Ismay and Desert Creek intervals of the Paradox Formation account for most of the production in the basin. Production from strata on the Uncompahgre uplift is mostly from the Cretaceous Castlegate Sandstone of the Mesaverde Group, fractured Mancos Shale, Emery and Ferron Sandstones of the Mancos Group, Dakota Sandstone, and Cedar Mountain Sandstone; and the Jurassic Salt Wash Member of the Morrison Formation and Entrada Sandstone of the San Rafael Group. On the San Rafael Swell, production is from the Upper Cretaceous Ferron Sandstone of the Mancos Group, the Jurassic Navajo Sandstone of the Glen Canyon Group and the fractured Triassic Moenkopi Formation. Other important reservoir rocks in the province include the Permian Kaibab Limestone and White Rim Sandstone, and the Devonian Ouray Limestone and McCracken Sandstone Member of the Elbert Formation.

Traps. Stratigraphic traps are common in the Paradox basin, particularly in the southern portion of the basin. These include biohermal carbonate mounds, often directly beneath an overlying anhydrite, and local porosity changes in carbonates and sandstone. Folded anticlines, faulted anticlines and salt anticlines are more common in the northern part of the basin. Subsalt fault blocks are a major trapping mechanism and may be present throughout the basin. On the Uncompahgre uplift and San Rafael Swell, anticlines, porosity pinch outs and fractured rocks beneath or within ductile shales are the main trapping mechanisms.

Source rocks. The source for hydrocarbons in Pennsylvanian, Mississippian, Devonian and some Mesozoic strata appears to be mostly from Pennsylvanian-age rocks, especially the numerous organic-rich shales in the Paradox Formation. Much of the production from Permian, Triassic, and Cretaceous rocks was derived from source beds in the Permian Kaibab Limestone, Triassic Moenkopi Formation and Cretaceous Mancos Shale. Other potential source beds include the Devonian Aneth Formation and the Proterozoic Chuar Group.

Future exploration. This province is still in an early stage of exploration. In addition to the numerous producing horizons known throughout the basin, shows of oil and gas have been recorded for many other horizons ranging in age from Tertiary intrusions to Cambrian sandstones. The producing carbonate mound trends of the Ismay and Desert Creek have not been fully explored and other carbonate mound trends in the Honaker Trail, Hatch, Akah, Barker Creek and Alkali Gulch are just now receiving attention. Fractured Cane Creek Shale has been a known producing interval in the basin for several years and yet only recently has been considered an important target for horizontal drilling. The Hovenweep Shale, Gothic Shale, Chimney Rock Shale and other shales in the Akah, Barker Creek and Alkali Gulch are also potentially productive in the basin and candidates for horizontal drilling technology. Sandstones that interfinger with the Honaker Trail Formation and the various subdivisions of the Paradox Formation must be considered potential future targets for oil and gas

P-545, SAN JUAN MOUNTAINS, SAN LUIS BASIN, LAS VEGAS-RATON BASIN AND SIERRA GRANDE UPLIFT
Generalized Stratigraphic Section

AGE	FORMATION	
	WEST	EAST
Cenozoic		
Oligocene		Farisita Cgl.
Eocene	Telluride-Blanco Basin Fm.	Huerfano Fm.
		Cuchara Fm.
Paleocene	Animas Fm.	Poison Canyon Fm.
		† Raton Fm.
Mesozoic		
Cretaceous		
Late	Kirtland Sh.	† Vermejo Fm.
	† Fruitland Fm.	† Trinidad Ss.
	Pictured Cliffs Ss.	Pierre Sh.
		Niobrara Fm.
	Lewis Sh.	Smoky Hill Marl Mbr.
	Mesaverde Gp.	Ft. Hays Ls. Mbr.
		Benton Group
	Mancos Sh.	Carlile Sh.
		Codell Ss. Mbr.
		Greenhorn Ls.
		Graneros Sh.
	* Dakota Ss.	* Dakota Ss.
Early	Burro Canyon Fm.	Purgatoire Fm.
Jurassic	Morrison Fm.	Morrison Fm.
	Brushy Basin Mbr.	Exeter Ss.
	Salt Wash-Ralston Creek Mbr.	
		Entrada Ss.
	Wanakah Fm.	
Triassic	Entrada Ss.	
		Johnson Gap Fm.
	Chinle Fm.	Dockum Gp.
Paleozoic		
Permian	Dolores-Santa Rosa Fm.	
	Bernal Fm.	Whitehorse Fm.
	Cutler Fm.	San Andres Ls.
		** Glorieta ("Lyons") Ss.
		Yeso Fm.
Pennsylvanian	* Rico Fm.	Sangre de Cristo Fm.
		† Magdalena Gp.
	Hermosa Fm.	Madera Fm.
Mississippian		Sandia Fm.
	Leadville Ls.	Meramec Gp.
	Terrero Fm.	
Devonian	Espiritu Santo Fm.	
Silurian		
Ordovician		
Cambrian		Arbuckle Gp.
	Ignacio Quartzite	Lamotte Ss.

* Currently producing
** Helium, nitrogen, carbon dioxide, etc.
† Potentially productive

P-550, PARADOX BASIN
Generalized Stratigraphic Section

AGE	FORMATION
Mesozoic	
Cretaceous	* Mesaverde Gp.
Late	Cliff House Fm.
	Menefee Fm.
	Point Lookout Fm.
	* Mancos Sh.
	Greenhorn Ls. Mbr.
	Graneros Sh. Mbr.
	* Dakota Fm.
Early	* Burro Canyon Fm.
Jurassic	* Morrison Fm.
	Brushy Basin Mbr.
	Westwater Canyon Mbr.
	Recapture Mbr.
	Salt Wash Mbr.
	San Rafael Gp.
	Bluff Ss.-Junction Creek Ss.
Triassic	Summerville Fm.
	Curtis Fm.
	Entrada Fm.
	Carmel Fm.
	Glen Canyon Gp.
	Navajo Fm.
	Kayenta Fm.
	Wingate Fm.
	Chinle Fm.
	Moenkopi Fm.
Paleozoic	
Permian	Cutler Group
	Kaibab Fm.
	* White Rim Ss.-DeChelly Ss.
	Organ Rock Fm.
	Cedar Mesa Ss. Mbr.
	Halgaito Fm.-Elephant Canyon Fm.
Pennsylvanian	Hermosa Gp.
	* Honaker Trail Fm.
	Paradox Fm.
	Pinkerton Trail Fm.
	Molas Fm.
Mississippian	* Leadville Fm.
Devonian	Ouray Fm.
	Elbert Fm.
	Upper Elbert Mbr.
	* McCracken Ss. Mbr.
	Aneth Fm.
Silurian	(missing)
Ordovician	(missing)
Cambrian	Lynch Dolo.
	Muav Fm.
	Bright Angel Fm.
	Ignacio Quartzite
	Tapeats Ss.

* Currently producing
No future productive reservoirs, not presently producing, are anticipated.

reserves in the basin. Many other reservoir intervals need to be examined in the Paradox basin, especially sandstones in the Cretaceous, Jurassic, Triassic, and Permian and the carbonates and sandstones in the Devonian and Cambrian. There are probably additional salt anticline traps as well as other structural traps and updip pinch outs to be discovered. Traps also possibly lie beneath laccolithic intrusions and in intrusive sills in the regions.

Accumulations in the Pennsylvanian biohermal mounds will probably be in the 25 to 75 Bcf range, while those in the Mississippian structural traps should be in the 50 to 500 Bcf range. Accumulations in the Permian Cutler and Pennsylvanian Honaker Trail formations should be in the 25 to 100 Bcf range.

P-555, SAN JUAN BASIN

The San Juan basin is one of the major gas provinces of the United States. It is bounded on the south by the Zuni uplift, on the west by the Defiance uplift, on the north by the San Juan uplift and on the east by the Nacimiento uplift. This structural basin covers 15,000 to 20,000 square miles and contains up to 15,000 feet of sedimentary rocks.

In the neighborhood of 20,000 wells have been drilled in the basin, of which approximately 17,000 are gas wells. Very little exploration drilling below the Cretaceous has been done outside of the Barker Dome Penn-Paradox and virtually nothing has been completed below 15,000 feet.

Probable resources are anticipated to be associated with established fields and will be discovered by extension of those fields. Due to a lack of aggressive "wildcatting" throughout the basin, the Possible category is separated from the Probable category. Generally, Speculative resources have not been considered in the San Juan basin.

Reservoir rocks. Production in the basin is mostly from Cretaceous sandstones. Upper Cretaceous reservoir rocks include the Pictured Cliffs Sandstone, Fruitland

Formation, Chacra Sandstone, Mesaverde Group (Cliff House and Point Lookout Members) and the Gallup Sandstone. With fracturing, some oil has been produced from the Mancos Shale. The Dakota Group is the dominant Lower Cretaceous reservoir in the basin. There is limited production from the Jurassic Entrada Sandstone and Morrison Formation. The Pennsylvanian Hermosa Formation produces oil, natural gas and helium along the western flank of the basin. Helium is found in the Devonian Ouray Limestone.

Traps. Stratigraphic trapping dominates in the basin. The specific trapping conditions include sandstone lenses, channels and bars and are influenced by differential compaction related to ancient topographic highs. The sedimentary rocks in the area are largely underpressured. Hydrodynamic traps have been recognized in the Gallup and Entrada Sandstones. Anticlinal traps are confined to the southwestern flank of the basin. Hydrodynamic conditions together with low permeability of reservoir rocks and the mechanism of gas generation are the main factors that have resulted in the formation of one giant gas field in the Cretaceous rocks of the central portion of the basin.

Potential source rocks. The Upper Cretaceous Mancos Shale and the Menefee Formation of the Mesaverde Group are the most likely sources for hydrocarbons found in the Upper Cretaceous reservoirs. The upper Jurassic Todilto Limestone may have been a source bed for the Dakota Group and for the Entrada Sandstone. The Hermosa Formation is another likely source bed, as are the coalbeds in the Fruitland Formation.

Producing trends. The Hogback monocline on the northwestern flank of the basin is a striking structural feature with several producing fields. Anticlines are confined to the rims of the basin and no folding has been detected in the central portion of the basin. Upper Cretaceous rocks in the central portion constitute basically one giant gas field, the Basin Dakota field, with a diameter of 100 miles and covering an area of over one million acres in which production occurs at depths shallower than 8,000 feet. Production in the Pictured Cliffs Sandstone is from elongate, northwest-trending sandstone stringers encased in shale.

Future exploration. Potential reservoir rocks below the Dakota Group include the Pennsylvanian section and the Jurassic. The Basin Dakota field may extend into Sandoval County. The southern and eastern flanks of the basin warrant further exploration.

Coalbed methane. The coalbeds in the basin are contained within an Upper Cretaceous nearshore marine and deltaic-transitional sequence that is as much as 8,000 feet thick. Coalbeds occur in this sequence in the Dakota Sandstone, Mesaverde Group, and Fruitland Formation. The multiple seams of coal in the Fruitland Formation, each of which can attain thicknesses of as much as 40 feet, constitute the most attractive coalbed methane resource target in the San Juan Basin. The Fruitland has historically been the chief interval targeted for coalbed methane development in the basin. However, some operators currently are showing increasing interest in exploiting gas in coals in the deeper Menefee Formation of the Mesaverde Group. Designated fields producing from the Fruitland Formation include the Ignacio-Blanco gas field in Colorado and the Basin Fruitland Coal Gas Pool and Cedar Hill field in New Mexico. The northern part of the basin contains the largest coalbed methane resource potential and is characterized by the greatest thickness of net Fruitland coal, as much as 80 feet, the highest heat flow and resulting high coal rank (up to low-volatile bituminous), and maximum in-place gas contents (200 to 450+ cf/ton of coal).

The development of coalbed methane in the San Juan basin is progressing at a rapid pace, with an estimated 2,500 wells drilled as of mid-1990, and an additional 500 wells scheduled to be drilled by the end of 1990.

The largest known coalbed methane producer in the world was completed by Meridian Oil in the Basin Fruitland field in Rio Arriba County, New Mexico, in 1990. The initial potential for the well was almost 23 MMcf/d, with several hundred barrels of water per day.

Total depths of coalbed methane wells in the Fruitland Formation range from 1,200 to 4,100 feet, with an average depth of most completions at ± 3,000 feet.

P-555, SAN JUAN BASIN
Generalized Stratigraphic Section

AGE		FORMATION
Cenozoic		
Eocene		San Jose Fm.
Paleocene		Nacimiento Fm.
		Ojo Alamo Ss.
Mesozoic		
Cretaceous		
Late		Kirtland Sh.
		Upper Shale Mbr.
		Farmington Ss. Mbr.
		Lower Shale Mbr.
	*	Fruitland Fm.
	*	Pictured Cliffs Ss.
		Lewis Sh.
	*	Mesaverde Gp.
		Cliff House Ss.
		Menefee Fm.
		Point Lookout Ss.
		Mancos Sh.
		Upper Shale-Gallup Ss. Mbr.
		Sanostee Mbr.
		Greenhorn Ls.
		Graneros Sh.
Early	*	Dakota Ss.
		Burro Canyon Fm.
Jurassic	*	Morrison Fm.
		Brushy Basin Mbr.
		Westwater Canyon Mbr.
		Recapture Mbr.
		Salt Wash Mbr.
		Summerville Fm.
		Todilto Ls.
	*	Entrada Ss.
		Carmel Fm.
Triassic	†	Wingate Ss.
		Chinle Fm.
		† Shinarump Cgl. Mbr.
		Moenkopi Fm.
Paleozoic		
Permian		DeChelly Ss.
	†	Cutler Fm.
Pennsylvanian	*	Hermosa Gp.
		Honaker Trail Fm.
		Paradox Fm.
		Pinkerton Trail Fm.
		Molas Fm.
Mississippian		Leadville Ls.
Devonian	**	Ouray Ls.
		Elbert Fm.
		Upper Elbert Mbr.
		McCracken Ss.
		Aneth Fm.
Silurian		(missing)
Ordovician		(missing)
Cambrian		Ignacio Quartzite

* Currently producing
** Helium
† Potentially productive

It is estimated that the in-place methane resource in the Fruitland coalbeds in the San Juan Basin totals approximately 50 Tcf; most of this resource occurs in the northern part of the basin. From 22 to 34 Tcf of gas in-place was estimated for the Menefee Formation.

The Fruitland coals in the San Juan basin contain at least 21 Tcf of recoverable coalbed methane resources.

P-560, SOUTHERN BASIN AND RANGE PROVINCE

This province covers southern Arizona and southwestern New Mexico. Marginally commercial production of natural gas or oil has been established in the Tularosa basin, Otero County, New Mexico, but is currently shut in. Carbon dioxide has been produced from the Estancia field in Torrance County, New Mexico. The Estancia field has not been produced since the 1940s. This area is considered a frontier region for petroleum exploration whose potential has not yet been determined.

Southern Arizona is a region of Precambrian rocks, lava flows and alluvial deposits. It has been postulated that the Western Thrust Belt extends from southernmost Nevada across southern Arizona, but this has not been confirmed by the results of limited drilling. If the Thrust Belt does exist in this region, then the potential for future production would be greatly increased. Additionally, discoveries of natural gas in Mexico, south of southwestern Arizona, raise some possibility for the establishment of production in westernmost Arizona. The Pedregosa basin of southeastern Arizona and southwestern New Mexico contains over 14,500 feet of sedimentary rocks and, thus, has some potential for production.

Central and southern New Mexico contains five sedimentary basins and the Lucero shelf. Sedimentary rocks representing all periods of the Paleozoic Era are present together with Jurassic and Cretaceous sedimentary rocks. Central New Mexico contains a thick Miocene-Pliocene sequence of continental sedimentary rocks and volcanics. The Tularosa (Orogrande) and Jornada del Muerto basins contain over 7,000 feet of sedimentary rocks. The Tularosa basin contains prospective Pennsylvanian biohermal limestones.

Reservoir rocks. Potential reservoir rocks in central New Mexico include the Cretaceous Dakota Formation and Gallup Sandstone; Jurassic Entrada Sandstone; Permian Glorieta Sandstone and San Andres Limestone; Pennsylvanian-Permian Sangre de Cristo and Abo Formations; and Pennsylvanian and Madera Limestone and Sandia Formation. South-central New Mexico reservoirs include the Pennsylvanian Magdalena Group; Mississippian Lake Valley Formation; Silurian Fusselman Formation; and Ordovician El Paso and Montoya Formations as well as undifferentiated Cretaceous, Permian and Pennsylvanian rocks. Potential reservoirs in the Pedregosa basin range in age from Cambrian to Early Cretaceous and include the Lower Cretaceous Mojado and the upper Bisbee Group; Permian Colina, Epitaph, Concha and Rainvalley Formations; Pennsylvanian Horquilla and Earp Formations; Mississippian Paradise and Escabrosa Formations; Devonian Martin Formation; Silurian Fusselman Formation; Ordovician El Paso and Montoya formations; and Cambro-Ordovician Bliss Sandstone and Abrigo Formation.

Traps. Potential traps are both structural and stratigraphic. Anticlinal and faulted anticlinal traps are present. Stratigraphic traps include bioherms, sandstone channels and lenses, carbonate-evaporite sequences and carbonate-red bed sequences. Thrust faulting, shear zones and block faulting form potential traps in southern Arizona.

Potential source rocks. Potential source rocks in central New Mexico are the Cretaceous Mancos Shale and Colorado Group, Jurassic Todilto Limestone, Permian San Andres Limestone, and Pennsylvanian Madera and Sandia Formations. In south-central New Mexico, the prospective source rocks are the Cretaceous Mancos Shale, Permian Hueco-Colina Formations, Pennsylvanian Gray Mesa Formation, Mississippian Lake Valley-Escabrosa Limestone and Devonian Percha Formation. In southern Arizona and southwestern New Mexico, possible source rocks include the Permian Colina, Epitaph, Concha, Scherrer, and Rainvalley Formations; Pennsylvanian Horquilla Formation; Mississippian Paradise Formation; and Devonian Percha Formation.

P-560, SOUTHERN BASIN AND RANGE PROVINCE
Generalized Stratigraphic Section

AGE	FORMATION	
	SOUTH & WESTERN ARIZONA	SOUTH & WESTERN NEW MEXICO
Cenozoic		
Miocene	various volcanics	Santa Fe Gp.
		Popotosa Fm.
Oligocene	various volcanics	volcanics
Eocene	various volcanics	Spears Fm.
		Baca Fm.
Paleocene	intrusives and volcanics	
Mesozoic		
Cretaceous		
Late	intrusives and volcanics	Mesaverde Fm. (West)
		Crevasse Canyon Fm.
		† Gallego Mbr. (Gallup) Ss.
		Mancos Sh.
		D-Cross Sh. Tongue
		Tres Hermanos Mbr.
		Lower Tongue
		† Sarten-Dakota Ss.
Early	Livingston Hills Fm. (West)	
	† Bisbee Group (South)	
	† Mojado Fm. (S.E.)	
	U-Bar Fm. (S.E.)	
	Hell-to-Finish Fm. (S.E.)	
	Bathtub Fm. (South)	
	Temporal Fm. (South)	
	McCoy Mountains Fm. (West)	
Jurassic	various intrusives and volcanics	
Triassic		Chinle Fm.-Dockum Gp.
Paleozoic		
Permian	Kaibab Ls. (West)	
	Naco Gp. (South)	
	† Rainvalley Fm.	
	† Concha Ls.	
	Coconino Ss. (West)	† San Andres Fm.
	Scherrer Fm. (South)	† Glorieta Ss.
	Concha (S.E.)	
	Supai Fm. (West)	
	† Epitaph Dolo.	Yeso Fm.
	† Colina Ls.	Abo Fm.
Pennsylvanian		Panther Seep Fm. (South)-
		† Madera Ls.-Magdalena Gp.
		† Lead Camp Ls.
	† Horquilla Fm.	Sandia Fm.
	Black Prince Ls. (South)	Helms Fm.
Mississippian	† Paradise Fm. (S.E.)	† Rancheria Fm. (South)
		Las Cruces Fm. (South)
	† Escrabosa Ls.	† Lake Valley Fm. (South)-Kelly Ls.
		Caballero Fm. (South)-Caloso Fm.
Devonian	Martin Fm.-Percha Sh.	Percha Sh.
Silurian		† Fusselman Dolo.
Ordovician	† Montoya Fm. (S.E.)	† Montoya Fm.
	† El Paso Fm. (S.E.)	† El Paso Gp.
	† Bliss Fm. (S.E.)	† Bliss Fm.
	† Abrigo Fm.	
Cambrian	Bolsa Quartzite	

† Potentially productive

565, PLATEAU PROVINCE AND BLACK MESA BASIN
Generalized Stratigraphic Section

AGE	FORMATION	
	PLATEAU PROVINCE	BLACK MESA BASIN
Cenozoic		
Miocene	Brian Head Fm.	
Eocene		
Paleocene	Wasatch Fm.	
Mesozoic		
Cretaceous		
Late		Mesa Verde Gp.
	Kaiparowits Fm.	Yale Point Fm.
		Wepo Fm.
	Wahweap Ss.	Toreva Fm.
	Straight Cliffs Ss.	Mancos Sh.
	Tropic Sh.	† Dakota Fm.
	† Dakota Ss.	
Jurassic	Morrison Fm.	Morrison Fm.
	San Rafael Gp.	San Rafael Gp.
	Cow Springs Ss.	Cow Springs Fm.
	Entrada Ss.	Entrada Ss.
	Carmel Fm.	Carmel Fm.
	Glen Canyon Gp.	Glen Canyon Gp.
	Navajo Ss.	Navajo Ss.
	Kayenta Fm.	Kayenta Fm.
	Moenave Fm.	Moenave Fm.
Triassic	Chinle Fm.	Chinle Fm.
	Shinarump Cgl. Mbr.	Shinarump Cgl. Mbr.
	Moenkopi Fm.	Moenkopi Fm.
Paleozoic		
Permian	Kaibab Ls.	Kaibab Fm.
	Toroweap Fm.	
	Coconino Ss.	** Coconino-DeChelly Ss.
		Cutler Fm.
	Hermit Sh.	Organ Rock Sh.
	Supai Fm.	Cedar Mesa Mbr.
		Halgaito Mbr.
Permo-Penn.	Supai Fm.	
Pennsylvanian		* Hermosa Gp.
	Molas Fm.	Molas Fm.
Mississippian	† Redwall Ls.	* Redwall Ls.
Devonian	† Temple Butte Ls.	Ouray Fm.
		* Elbert Fm.
		* Aneth Fm.
Cambrian		Lynch Dolo.
	Tonto Gp.	Tonto Gp.
	Muav Ls.	Muav Ls.
	Bright Angel Sh.	Bright Angel Sh.
	† Tapeats Ss.	† Tapeats Ss.
Precambrian	Grand Canyon "Supergroup"	

* Currently producing
** Inert gas, helium, etc.
† Potentially productive

P-565, PLATEAU PROVINCE AND BLACK MESA BASIN

This province covers northern Arizona and part of southern Utah. The province includes the Colorado Plateau, the Black Mesa basin and the Defiance uplift. Production in the province is presently confined to the Defiance uplift. The Colorado Plateau consists of a thick series of sedimentary rocks that have undergone relatively little deformation since their deposition. The section does not contain favorable potential source rocks and there are relatively few potential traps, so the Colorado Plateau has little or no potential for future natural gas production. The Black Mesa basin is a structural downwarp instead of a depositional sedimentary basin and has little or no potential for future natural gas production.

Reservoir rocks. Current production comes from rocks ranging in age from Devonian to Cretaceous. The reservoir formations include Cretaceous sandstones; Permian Coconino Sandstone; Pennsylvanian Paradox and Naco Formations; Mississippian Leadville Limestone; and Devonian Aneth and McCracken Formations. All intervals produce both oil and natural gas. Helium is also produced from both the Coconino Sandstone and the Devonian reservoirs.

Traps. Biohermal limestones are common in the Aneth Formation. Variable porosity and permeability is a common stratigraphic trap. Both anticlines and faulted anticlines are prospective targets. Production has also been developed in units adjacent to a Tertiary sill.

Potential source rocks. The probable source beds for the province are carbonate rocks, including the Pennsylvanian Paradox and Naco Formations and the Devonian Aneth and Martin Formations.

Future exploration. Much of the province apparently has little potential for natural gas production. The Defiance uplift, however, has been sparsely explored and, undoubtedly, contains more stratigraphic traps. Mesozoic intervals have been largely ignored and contain potential reservoirs.

P-570, SWEETGRASS ARCH AND CENTRAL MONTANA

This region covers the central portion of Montana. It contains a thick series of sedimentary rocks of Mesozoic and Paleozoic age, including both clastic and carbonate rocks. Numerous domes, arches, and young intrusive mountain complexes dot the province. Both associated/dissolved and nonassociated gas is produced in this region.

Reservoir rocks. Numerous sandstone reservoir rocks of Cretaceous age include the Judith River and Eagle Members of the Pierre Shale, the Bow Island Member of the Blackleaf Formation, Frontier Formation, Cat Creek, Viking, Moulton, Sunburst, Lakota, and Cutbank Sandstones. On the Sweetgrass arch, the Jurassic Swift and Sawtooth Formations of the Ellis Group are productive. Paleozoic units of interest are the Pennsylvanian Amsden Group and Tyler Formation; Mississippian Madison Group; and Devonian Nisku (Birdbear) Formation.

Traps. Anticlines and domes form traps for all stratigraphic intervals throughout the region. Faults are numerous due to various tectonic events in the area and provide traps for many units. In all Cretaceous units and in the Tyler Formation, traps occur in sandstone channels and lenses. Porosity variations occur in all intervals. In the Madison, buried topographic traps can be found. At various intervals, angular unconformities are the trapping mechanism. Hydrodynamic tilting of oil/water and gas/water contacts occurs in the south-central portion of the province.

Potential source rocks. Many Jurassic and Cretaceous units are potential source rocks. These are the Montana Group, Colorado Group, Inyan Kara Group, and Rierdon Formation. Paleozoic sources are probably the Tyler; Mississippian Heath and Lodgepole Formations; and Devonian-Mississippian Cottonwood Canyon and Bakken Formations.

P-570, SWEETGRASS ARCH AND CENTRAL MONTANA
Generalized Stratigraphic Section

AGE	FORMATION		
	WEST FLANK	EAST FLANK	CENT. MONTANA
Cenozoic			
	Tertiary sedim. rocks	Tertiary sedim. rocks	
Paleocene	Willow Creek Fm.		Ft. Union Fm.
Mesozoic			
Cretaceous			
Late	St. Mary River Fm.	Hell Creek Fm.	Hell Creek Fm.
		Fox Hills Ss.	Fox Hills Ss.
	Horsethief Ss.	Bearpaw Sh.	Bearpaw Sh.
		Judith River Fm.	Judith River Fm.
	Two Medicine Fm.	Claggett Sh.	Claggett Sh.
	* Virgelle-Eagle Ss.	* Virgelle-Eagle Ss.	* Eagle Ss.
	Telegraph Creek Fm.	Telegraph Creek Fm.	Telegraph Creek Fm.
	Marias River Fm.		
	Kevin Sh. Mbr.	Niobrara Fm.	Niobrara Fm.
	Ferdig Sh. Mbr.	Carlile Fm.	Carlile Fm.
	Cone Calc. Mbr.	Greenhorn Fm.	Greenhorn Fm.
	Floweree Mbr.		Belle Fourche Sh.
Early	* Blackleaf Fm.		
	Bootlegger Mbr.	Mowry Sh.	Mowry Sh.
	Vaughan Mbr.	* Bow Island Ss.	Muddy Ss.
	Taft Hill Mbr.		Skull Creek Sh.
	Flood Mbr.	* Dakota Ss.	Dakota Ss.
	Kootenai Fm.	Kootenai Fm.	Kootenai Fm.
Jurassic	* Morrison Fm.	* Morrison Fm.	* Morrison Fm.
	* Swift Fm.	* Swift Fm.	* Swift Fm.
	Rierdon Fm.	Rierdon Fm.	Rierdon Fm.
	* Sawtooth Fm.	* Piper Fm.	* Piper Fm.
Paleozoic			
Pennsylvanian			Tensleep Fm.
			* Amsden Gp.
Mississippian			* Big Snowy Gp.
	Castle Reef Dolo.	Castle Reef Dolo.	Charles Fm.
	* Mission Canyon Ls.	* Mission Canyon Ls.	* Mission Canyon Ls.
	Lodgepole Ls.	Lodgepole Ls.	Lodgepole Ls.
Devonian	Exshaw Fm.	Exshaw Fm.	
	Three Forks-Potlach Fm.	Three Forks Fm.	
	† Jefferson Gp.	† Jefferson Gp.	† Jefferson-Duperow Gp.
	Souris River Fm.	Souris River Fm.	
Silurian			
Ordovician			Red River Fm.
Cambrian			Snowy Range Fm.
	Devils Glen Dolo.	Upper Emerson Fm.	Pilgrim Ls.
	Switchback Sh.	Pentagon Sh.	
	Steamboat Ls.		Park Sh.
	Pagoda Ls.		Meagher Ls.
	Dearborn Ls.		Wolsey Fm.
	Damnation Ls.	† Flathead Ss.	† Flathead Ss.
	Gordon Sh.		
	† Flathead Ss.		
Precambrian	Belt Supergroup		Belt Supergroup

* Currently producing
† Potentially productive

P-575, MONTANA FOLDED BELT
Generalized Stratigraphic Section

AGE	FORMATION
Cenozoic	Various volcanics & conglomerates
Mesozoic	
Cretaceous	
Late	Montana Gp.
	Willow Creek Fm.
	St. Mary River Fm.
	Two Medicine Fm.
	† Virgelle Fm.
	Telegraph Creek Fm.
	Colorado Gp.
	Marias River Sh.
Early	Blackleaf Fm.
	Vaughan-Dunkleburg Mbr.
	Taft Hill Mbr.
	Flood Mbr.
	† Kootenai Fm.
Jurassic	Morrison Fm.
	Ellis Gp.
	† Swift Fm.
	Rierdon Fm.
	Sawtooth Fm.
Triassic	Thaynes Fm.
	Woodside Fm.
	Dinwoody Fm.
Paleozoic	
Permian	Shedhorn Ss.
	Phosphoria Fm.
	Park City Fm.
Pennsylvanian	† Quadrant Fm.
	Amsden Fm.
Mississippian	Big Snowy Gp.
	* Madison Gp.
	Mission Canyon Ls.
	Lodgepole Ls.
Devonian	Three Forks Fm.
	† Jefferson Formation
	Maywood Fm.
	Beartooth Butte Fm.
Ordovician	Bighorn Dolo.
Cambrian	Red Lion-Snowy Range Fm.
	Hasmark Dolo.
	Silver Hill-Wolsey Fm.
	Flathead Ss.
Precambrian	Mission Gp.
	Helena Dolo.
	Empire Fm.
	Spokane Fm.
	Prichard Fm.

* Currently producing
† Potentially productive

P-575, MONTANA FOLDED BELT

This region includes the northern projection of the Wyoming-Utah-Idaho Thrust belt. The configuration of the region was formed during the Laramide Orogeny in late Cretaceous and early Tertiary time. This deformation involving both Paleozoic and Mesozoic rocks, proceeded from west to east and progressively older sedimentary rocks are involved to the west where more faulting has occurred. Major thrust faults, and imbricating minor thrusts, form a series of complexly folded and faulted thrust packages. Folding is common in all intervals. In various portions of the province, several older, northeast-trending fault blocks affect the thickness of the strata.

Southwestern Montana underwent deformation of a different nature starting with major vulcanism during Campanian time. This was followed by emplacement of the Boulder batholith in latest Cretaceous time. The western portion of the province is made up of mountain belts.

Potential reservoir rocks. The Mississippian Madison Group is presently the only productive interval in this region. Other prospective units are Paleocene sandstone; Cretaceous Fox Hills Sandstone, Eagle Sandstone Member of the Pierre Shale, Cloverly Formation, Cat Creek Sandstone, Lakota Formation, and Cutbank Sandstone Member of the Kootenai Formation. Possible Paleozoic reservoirs are the Pennsylvanian Quadrant Formation and Shedhorn Sandstone; and the Devonian Three Forks and Jefferson Formations. It is also possible that fractured Proterozoic Belt Supergroup strata will prove to be productive.

Traps. Major trapping mechanisms in the area are formed by thrust faults, folds and faulted folds. Traps occur in sandstone bars and channels within the Cretaceous and Tertiary units. Facies changes in Paleozoic carbonate rocks are a possible trapping mechanism.

Potential source rocks. Possible source rocks include Paleocene shale; Cretaceous Montana and Colorado Groups; Triassic Thaynes Formation; Pennsylvanian Phosphoria Formation; and Devonian-Mississippian Exshaw and Sappington Member of the Three Forks Formation. Possible Precambrian source beds include the black shale strata in the Belt Supergroup of Middle Proterozoic age.

P-580, SNAKE RIVER BASIN

The Snake River downwarp is an arcuate basin whose borders lie on either side of the Snake River and roughly parallel the river. The basin lies between the overthrust fold belts of east-central and southeast Idaho and extends to the southwestern edge of Idaho, as far as, but not including, the Hells Canyon area.

The rock section is composed of numerous extrusive volcanic flows and air-fall material interbedded with fluvial and lacustrine clastic deposits more prominent in the southwestern area. Some black shales and a few coalbeds are included in the section.

Numerous gas shows, ranging in quality from 750 to 1,400 Btu per cubic foot have been found through seeps and in wells. Juvenile bitumens, apparently in place, have also been noted. Reservoir rocks and apparent source rocks have been identified. Trapping mechanisms pose a question. Drilling has been sparse to date and no commercial discoveries have been made, but there is continued industry interest spurred by shows. The potential for commercial natural gas accumulations is difficult to define. The exploration risk is high, but there are enough favorable indicators to hold out promise for the basin.

P-590, WYOMING-UTAH-IDAHO THRUST BELT

This area is made up of allochthonous sheets of Paleozoic and Mesozoic sedimentary rocks overlain by autochthonous Tertiary sedimentary rocks. Thrusting occurred in Cretaceous through early Tertiary time. This region is composed of a series of thrust sheets internally dissected by smaller thrust and larger normal faults. Structural complexity and lateral variations in rock type make exploration difficult. Thrust sheets are commonly tightly folded and faulted in areas of hanging-wall cutoff and truncation and gently dipping in intervening areas. In some areas detachment occurs within a thrust sheet and structural styles differ above and below this horizon. The stacked sediment package is over 40,000 feet thick in the western portion of the province and 14,000 feet thick in the east. Production is presently confined to the southwesternmost portion of Wyoming and a small portion of adjacent Utah; all commercial production is on the Absaroka thrust sheet. Oil, associated/dissolved gas, nonassociated gas and condensate are produced. Nonassociated gas from Paleozoic carbonate reservoirs is sour. The Idaho portion of the province has not proven productive despite a fair number of exploratory tests.

Reservoir rocks. Sixteen units ranging in age from Ordovician to Late Cretaceous are presently producing in this province. The Mississippian Madison Limestone, Triassic-Jurassic Nugget Sandstone and Permian-Pennsylvanian Weber Sandstone and Ordovician Bighorn Dolomite are major targets in this region. Other reservoirs include the Upper Cretaceous Frontier Formation; Jurassic Stump Sandstone and Twin Creek Limestone; Triassic Thaynes Limestone, Woodside Formation and Dinwoody Formation; Permian Phosphoria Formation; and Devonian Darby Formation.

Traps. Structural trapping affects all stratigraphic intervals and includes folded and thrusted anticlines. Potential stratigraphic traps include carbonate mounds in the Thaynes Limestone, changes in carbonate facies, and pinch outs in Upper and Lower Cretaceous sandstones.

Potential source rocks. The main source of hydrocarbons is Cretaceous marine shale. Other possible sources include the Phosphoria, Thaynes, and Devonian Three Forks Formations.

P-590, WYOMING–UTAH–IDAHO THRUST BELT
Generalized Stratigraphic Section

AGE	FORMATION
Cenozoic	
Miocene	Salt Lake Fm.
Eocene	Norwood Tuff
	Fowkes Fm.
	Green River Fm.
	Wasatch Fm.
Paleocene	Evanston-Sublette Range Fm.
Mesozoic	
Cretaceous	Adaville Fm.
Late	† Hilliard Fm.-Shurtliff Ss.
	† Frontier Fm.
Early	† Aspen Sh.
	Sage Junction Fm.
	Quealy Fm.
	† Cokeville-Wayan Fm.
	* Bear River Fm.
	Thomas Fork Fm.
	Smiths Fm.
	Gannett Gp.
Jurassic	* Stump Ss.
	Preuss Ss.
	* Twin Creek Ls.
	* Nugget Ss.
Triassic	* Ankareh Fm.
	* Thaynes Ls.
	Woodside Fm.
	* Dinwoody Fm.
Paleozoic	
Permian	* Phosphoria Fm.
Pennsylvanian	Wells Fm.-Weber Ss.
Penn.-Mississippian	Amsden Fm.
Mississippian	Madison Ls.
	* Mission Canyon Ls. Mbr.
	* Lodgepole Ls. Mbr.
Devonian	* Darby Fm.
Silurian	Laketown Dolo.
Ordovician	* Bighorn Dolo.
Cambrian	Gallatin Ls.
	Gros Ventre Fm.
	Flathead Ss.

* Currently producing
† Potentially productive (subthrust-footwall)

Table 13. Estimated resources of natural gas for provinces of the Rocky Mountain Area, December 1990 (billion cubic feet)

PROVINCE	PROBABLE			POSSIBLE			SPECULATIVE		
	Min.	M. likely	Max.	Min.	M. likely	Max.	Min.	M. likely	Max.
Onshore, less than 15,000'									
P-500, Williston basin	242	819	1,870	277	554	924	67	292	563
P-510, Powder River basin	700	1,100	1,500	1,500	2,300	2,800	300	500	700
P-515, Big Horn basin	500	750	1,000	400	550	1,000	*	*	*
P-520, Wind River basin	600	1,250	1,800	1,888	6,520	12,000	*	*	*
P-530, Greater Green River basin	7,600	9,400	11,700	7,200	11,400	18,500	200	1,800	7,000
P-535, Denver basin, Chadron arch and Las Animas arch	1,700	2,900	4,900	900	2,100	4,400	*	45	200
P-540, Uinta/Piceance basins, Park and Eagle basins	4,224	7,705	11,594	3,566	4,881	6,097	189	418	1,910
P-545, San Juan Mountains, San Luis/Raton basins, etc.				100	400	1,000	*	700	1,400
P-550, Paradox basin	50	200	300	500	1,000	3,500	100	500	1,000
P-555, San Juan basin	1,000	1,500	2,500	300	500	1,000	*	*	*
P-560, Southern Basin and Range province				*	1,400	5,600	*	*	50
P-565, Plateau province, Black Mesa basin	*	*	50	*	50	100	50	250	500
P-570, Sweetgrass arch	1,800	2,300	3,200	1,567	2,090	2,640	990	1,320	1,620
P-575, Montana Folded Belt	*	*	100	*	1,000	2,000	*	2,500	3,500
P-580, Snake River basin							100	200	300
P-590, Wyoming-Utah-Idaho Thrust Belt	1,000	2,300	3,400	500	2,400	6,000	1,300	4,000	10,000

*Negligible quantity of natural gas estimated.

Table 13. Estimated resources of natural gas for provinces of the Rocky Mountain Area, December 1990 - (billion cubic feet) (continued)

PROVINCE	PROBABLE			POSSIBLE			SPECULATIVE		
	Min.	M. likely	Max.	Min.	M. likely	Max.	Min.	M. likely	Max.
Onshore, 15,000- 30,000'									
P-500, Williston basin				41	98	146			
P-510, Powder River basin							500	1,000	2,000
P-515, Big Horn basin	100	150	450	500	650	1,300	*	400	700
P-520, Wind River basin	2,950	3,400	4,250	2,500	3,100	5,100	*	400	700
P-530, Greater Green River basin	3,700	4,200	4,700	11,600	16,900	24,800	100	800	5,600
P-535, Denver basin, Chadron arch and Las Animas arch									
P-540, Uinta/Piceance basins, Park and Eagle basins	200	500	1,500	100	200	800	100	300	2,100
P-545, San Juan Mountains, San Luis/Raton basins, etc.							*	300	600
P-550, Paradox basin									
P-555, San Juan basin							*	*	*
P-560, Southern Basin and Range province							*	*	*
P-565, Plateau province, Black Mesa basin							*	*	*
P-570, Sweetgrass arch									
P-575, Montana Folded Belt							*	*	*
P-580, Snake River basin									
P-590, Wyoming-Utah-Idaho Thrust Belt	3,000	5,000	8,000	800	1,200	3,000	1,000	2,200	4,000
Sum of Most Likely Estimates									
Onshore, 0-15,000'		30,224			37,145			12,525	
Onshore, 15,000 - 30,000'		13,250			22,148			5,400	
Onshore, All Depths		43,474			59,293			17,925	
GRAND TOTAL FOR AREA		43,474			59,293			17,925	

*Negligible quantity of natural gas estimated.

	Probable Mean	Possible Mean	Speculative Mean
Mean values by statistical aggregation	45,218	65,413	22,455

P-600
WASHINGTON
P-960-961
PACIFIC OFFSHORE
(0-200m)SHELF
(200-1000m)SLOPE
P-610
EASTERN COLUMBIA BASIN
OREGON-
WASHINGTON
COASTAL BASINS
OKANOGAN
PROVINCE
OREGON
IDAHO
MO
GREAT BASIN,
SIERRA NEVADA,
KLAMATH MTNS.-
SOUTHERN OREGON
P-620
SACRAMENTO
BASIN
NEVADA
PACIFIC
P-640
P-650
SAN JOAQUIN BASIN
CALIFORNIA COASTAL BASINS
P-660
P-630
SOUTHEASTERN
CALIFORNIA BASINS
ARIZ
BAJA

PACIFIC AREA

During 1989 and 1990, exploration activity within the Pacific region continued at low levels. The Sacramento Valley still accounts for the majority of gas exploratory drilling in the Pacific region. The Sacramento Valley experienced better exploratory drilling with numerous discoveries of new fields, new pools and extensions. The more significant exploration and development achievements in the Sacramento Valley included:

1. A deeper pool discovery of significant size was made in the Winters Sand in the Bunker gas field. Nine wells had been completed, and casing had been set on two additional wells, which are awaiting completion.
2. The discovery of the River Garden Farms gas field and continued development of the Knights Landing and Cache Creek gas fields. All these fields produce from the Starkey Sands.
3. Three additional wells were completed at Ord Bend, a small field that was discovered and developed in 1943-44. Although this is not a big discovery, it is illustrative of the potential adjacent to areas thought to be fully developed.
4. Two wells were completed at South Putah Sink, a new field discovery with completion in the Winters Sand. Additional completions are likely.
5. New fields were discovered in Butte County at East Ord Bend (production from the Princeton Gorge Fill), in Sacramento County at Southeast Merritt Island (production from the Winters Sand) and in Solano County at South Davis (production from the Winters Sand). Each of these are single well discoveries that have potential significance but had not yet been followed by additional drilling as of the end of 1990.
6. Continued extension and development of production at Grimes and adjacent gas fields with completions primarily in the F Zone. This includes the Pierce Road gas field in Sutter County, which now has nine completed wells.

Gas production in the San Joaquin Valley is predominantly associated gas, and, therefore future potential reserves are dependent on oil exploration. In the last two years, oil exploration has been very limited. Most drilling activity in this portion of the basin has been field extensions, with reasonably good success in the south end of the San Joaquin Valley.

Of more significance for future gas potentials have been discoveries in the northern San Joaquin Valley. A discovery of deeper pool gas production in the Gill Ranch field in Madera County and unevaluated new field discoveries in Merced County hold considerable promise for nonassociated gas potential in the region. Additionally, production has been established from the Blewett Formation at the Marrill Avenue field in Fresno County. These discoveries in the northern San Joaquin Valley give new impetus to exploration in an area of primarily nonassociated natural gas production.

Exploration activity in the onshore coastal basin areas continued to be very slow during 1989 and 1990, with only sporadic exploration drilling occurring in four of the six basins (Los Angeles, Santa Maria, Ventura and Salinas/Cuyama). In the Los Angeles Basin, some exploration occurred along the Whittier and Newport-Englewood fault tends and Castaic area. Exploration was limited to the Rincon and Timber Canyon areas in the Ventura basin. In the Santa Maria basin, a single new pool discovery was made in the Los Alamos area. This lack of activity is due not only to economics but to ever increasing surface restrictions and regulations, as well as an overall industry reassessment of reserves and potential. A preponderance of the drilling in the coastal areas was limited to development within existing field limits.

The majority of all natural gas produced in the onshore coastal basins is associated. During 1989 and 1990, this overall production of natural gas decreased, as did that of oil. With this annual decrease in gas production and the lack of substantial success from the limited exploration activity, the estimated resources of natural gas for the onshore coastal basins were assessed to be lower than that projected prior to 1989.

P-600, OREGON-WASHINGTON COASTAL BASINS, OKANOGAN PROVINCE

This province presently has one productive field, Mist field in Clatsop County, Oregon. Potential in the region is basically confined to the coastal region. The coastal region is composed largely of Tertiary rocks (both marine and continental) with some interbedded lava flows and is covered in places with glacial drift.

The Olympic Mountains are mostly a metamorphic complex with some lava flows. The Okanogan Highlands of northern Washington are a combination of intrusive and extrusive igneous rocks with metamorphosed regions. Historically there have been two other fields in the province: Ocean City and Bellingham. Ocean City in Grays Harbor County, Washington, produced approximately 12,500 barrels in four years from a fractured Oligocene sandstone. The Bellingham gas field in Whatcom County, Washington, locally produced gas from sandstone lenses in glacial deposits.

Reservoir rocks. Present production is from the Eocene Cowlitz Formation. Potential reservoir rocks are the Miocene-Pliocene Quinault Formation, the Miocene Astoria Formation, the Miocene-Oligocene Yaquina Sandstone, and the Eocene Coaledo Formation.

Traps. The main traps in the area occur in sandstone lenses. Unconformity truncations affect Pliocene and late Eocene rocks. Shale diapirs with accompanying onlaps and faults form potential traps in Miocene and Pliocene rocks.

Source rocks. Potential source rocks in this area are the Miocene Nye Shale, the Oligocene Alsea Formation and the Eocene Coaledo and Yamhill Formations.

P-610, EASTERN COLUMBIA BASIN

This province has very little natural gas potential. Most of the region is covered with thick plateau basalts. The Cascade Range, a series of volcanoes, are also included in this region. Historically there has been one gas field in this province, Rattlesnake Hills. Production was from vesicular basalt. The trap was a faulted anticline with thin shale acting as the seal. Total production was 1 Bcf of gas. The source rock is unknown. There is some possibility of production from reservoir rocks and source rocks lying below the thinner portions of the lava flows.

P-620, GREAT BASIN, SIERRA NEVADA, KLAMATH MOUNTAINS AND SOUTHERN OREGON

The region contains a thick Paleozoic section with lesser amounts of Mesozoic and Tertiary rocks. The Great Basin is composed of numerous horst and graben blocks that are internally folded and faulted. This complicates the stratigraphy and makes exploration more difficult. Present oil production is limited to five fields in Nevada, four of these in Railroad Valley. One of the wells in Railroad Valley has the highest rate of oil production of any well in the lower 48 states. There is also limited production in the Klamath Mountains. The province is a region of major mineral exploration also.

Reservoir rocks. Past production has been from freshwater limestones and tuffs of the Eocene Sheep Pass Formation. Other potential reservoirs are the Permian Meade Park Shale Member of the Phosphoria Formation, the Mississippian Deseret Limestone and Chainman Shale and the Devonian Pilot Shale. Other Mesozoic and Paleozoic sandstones and carbonate rocks may be potential reservoirs.

Traps. Stratigraphic traps, including sandstone lenses and changes in carbonate facies, are probable traps in this area. Folds and faults are very likely traps. Combination traps may be most important.

Source rocks. Potential source rocks include the Tertiary Elko Formation and Sheep Pass Formation; the Upper Cretaceous Newark Canyon Formation; the Permian Meade Park Shale Member of the Phosphoria Formation; the Mississippian Deseret Limestone; and Chainman Shale; the Devonian Pilot Shale and Woodruff Formation; and the Ordovician Vinini Formation. Source rocks are moderately mature to severely altered in the province. Other shales and carbonate rocks may be potential source rocks in the area.

P-630, SOUTHEASTERN CALIFORNIA BASINS

This province includes the Mojave Desert, Salton Trough and Peninsular Ranges. Little is known about this nonproductive province. Marine Tertiary rocks are potential targets near San Diego adjacent to the San Andreas fault and along the Colorado River. The region has limited hydrocarbon potential.

P-640, SACRAMENTO BASIN

The Sacramento basin is the northern portion of California's Great Valley. It is bounded on the east by the Sierra Nevada, on the northeast by the Cascade Range, on the north by the Klamath Mountains and on the west by the Coastal Ranges. It is separated from the San Joaquin basin by the Stockton arch. The Sacramento basin is a structural and stratigraphic basin about 200 miles long and 70 miles wide. Over 30,000 feet of sediments were deposited in the deepest portion of the basin. These rocks are Late Cretaceous and younger in age. Much of the basin is veneered with Holocene and Pleistocene alluvial deposits. This is an important natural gas province; most of it is nonassociated gas.

Although more than 8,000 wells have been drilled in the Sacramento basin, only a relatively small number have made significant penetration beneath the base of the Upper Cretaceous F Zone or below 11,000 feet. These relatively unexplored deeper portions of the basin are considered less attractive because of the generally poor reservoir quality of the rocks and superpressures with hydrostatic gradients in excess of 0.7 psi/foot in many areas. The testing of these deeper formations and portions of the basin has not been adequate to condemn them as exploration objectives.

P-620, GREAT BASIN, SIERRA NEVADA, KLAMATH MTNS.-SOUTHERN OREGON
Generalized Stratigraphic Section

AGE	FORMATION			
	NORTHWEST–2**	SOUTHWEST–4, 5**	CENTRAL–9**	E.-CENTRAL–17**
Cenozoic				
Miocene	various volcanics		various volcanics	various volcanics
Pliocene	various volcanics		various volcanics	various volcanics
Oligocene		various tuffs	various volcanics	various volcanics
Eocene			Sheep Pass Fm.	
				White Sage Fm.
Paleocene				
Mesozoic				
Cretaceous	igneous complex	igneous complex	igneous complex	
Jurassic	volcanic complex	igneous complex	igneous complex	
		Dunlap Fm.	Aztec Ss.	
		Sunrise Fm.	Kayenta equiv.	
	Boyer Ranch Fm.			
	Lovelock-Muttlebury Fm.			
Triassic	various sands	Gabbs Fm.	Chinle Fm.	
	Auld Lang Syne Gp.	Luning Fm.		
	Cane Spring Fm.			
	Congress Canyon-Augusta Mt. Fm.			
	Prida Fm.			
	Weaver Rhyolite	Candelaria Fm.	Thaynes Fm.	Thaynes Fm.
Paleozoic				
Permian	Limerick Greenstone	Mina-Diablo-Black Dyke Fm.	Carlin Canyon Fm.	Park City Gp.
	Edna Mt. Fm.		Beacon Flat Fm.	Loray Fm.
			Buckskin Mt.-Carbon Ridge Fm.	Pequop Fm.
				Ferguson Mt. Fm.
Permian-Penn.	Antler Peak Ls.		Strathearn Fm.	Strathearn Fm.
Pennsylvanian	Highway Ls.-Battle Fm.	unnamed chert	Tomera Fm.	Ely Fm.
			Moleen Fm.	
		Rest Spring Sh.		
Mississippian	Goughs Canyon Fm.	Perdido Fm.	Diamond Peak Fm.	
		Tin Mt. Ls.	Chainman Fm.	Chainman Fm.
			Joana Fm.	Joana Fm.
Devonian	Pilot Sh.	Squares Tun. beds	Pilot Sh.	Pilot Sh.
			Devils Gate Ls.	Guimette Fm.
	Wenban Ls.	Sunday Canyon Fm.	Nevada Fm.	Simonson Dolo.
				Sevy Dolo.
Dev.-Silurian	Roberts Mt. Ls.	Vaughn Gulch Ls.	Lone Mt.-Roberts Mt. Dolo.	Laketown Dolo.
Silurian				
Ordovician	Henson Creek Fm.	Ely Springs Dolo.	Henson Creek Fm.	Ely Springs Dolo. (upp. & lwr.)
	Eureka Qtzite.	Johnson Springs Fm.	Eureka Qtzite.	Eureka Qtzite.
		Barrel Springs Fm.		Crystal Peak Dolo.
		Mzourka-Pogonip Gp.		Watson Ranch Qtzite.
Cambrian	Comus Fm.	Emigrant Fm.-Bonanza King Dolo.	Pogonip Fm.	Pogonip Fm.
	Harmony Fm.		Windfall Fm.	Notch Peak Fm.
	Paradise Valley Chert		Dunderberg Fm.	Orr Fm.
	Preble Fm.		Hamburg Dolo.	Wahwah Sum. Fm.
				Trippe Fm.
			Secret Canyon Fm.	Pierson Cove Fm.
			Geddes Ls.	Eye-of-Needle Fm.
		Mule Spring Ls.	Eldorado Dolo.	Abercrombie Fm.
	Osgood Mt. Qtzite.-Pioche Sh.-Prospect Mt. Qtzite.	Harkless Fm.	Pioche Sh.	Pioche Sh.
		Poleta Fm.	Prospect Mt. Qtzite.	Prospect Mt. Qtzite.
		Campito Fm.		

** Numbers refer to Great Basin COSUNA chart general locations.

P-640, SACRAMENTO BASIN
Generalized Stratigraphic Section

AGE		FORMATION
Cenozoic		
Pliocene	*	Tehama Fm.
Miocene-Pliocene		Sycamore-Mehrten Fm.
Miocene		San Pablo Gp.
		Monterey Gp.
		Claremont Sh.
		Sobrante Ss.
		Valley Springs Fm.
Oligocene		Kirker Fm.
Eocene	*	Markley Fm.
	*	Nortonville Sh.
	*	Domengine Fm.
	*	Capay Fm.
Paleocene	*	Martinez Fm.
Mesozoic		
Cretaceous		
Late		Mokelumme River Sands-Deer Valley Fm.
		H & T-Moreno Sh.
		Upper Delta Sh.
	*	Starkey Sands
		Sawtooth-Upper Delta Sh.
	*	Winters Ss.
	*	Lathrop Sand-Lower Delta Sh.
	*	Sacramento Sh.
	*	Kione Ss.–Forbes Sh.
		Dobbins Sh. Mbr.
	*	Guinda Ss.
		Funks Fm.
	†	Sites Fm.
		Yolo Fm.
	†	Venado Fm.
Early		Budden Canyon Fm.
E. Cret.-Jurassic		Stony Creek Fm.
Jurassic(?)		Franciscan Series

* Currently producing
† Potentially productive

Reservoir rocks. The producing horizons in this province are Late Cretaceous to Eocene in age. All are sandstones and include the Eocene Domengine Sandstone and Capay Formation; the Paleocene Meganos and Martinez Formations and the Upper Cretaceous Starkey, Winters, and Kione Sandstone and Forbes Shale.

Traps. In this province, most gas accumulations are found in structural/stratigraphic trap combinations. Anticlines and faulted anticlines are very important. Most sandstones are either lenticular in nature or are submarine canyon deposits. Truncations and onlapping occur.

Source rocks. Numerous organic-rich shales were deposited with and between the sandstone units. Potential source rocks include the Starkey, Winters, and Kione Sandstones and Forbes Shale. Many Paleocene and Eocene shales may also be source rocks.

P-650, SAN JOAQUIN BASIN

The San Joaquin basin occupies the southern portion of California's Great Valley. It is an asymmetrical structural and stratigraphic basin with its axis in the western part of the valley and is approximately 250 miles long and 50 to 60 miles wide. It is bounded on the east by the Sierra Nevada, on the south by the Tehachapi Mountains, on the west by the Coast Ranges and on the north by the Stockton arch. More than 31,000 feet of Cretaceous and younger sedimentary rocks were deposited in this basin. Most of this is marine shale and sandstone, though continental deposits occur in younger intervals. The eastern portion of the basin is gently folded and faulted. The western portion is highly folded and thrust faulted. Sedimentary rocks were deposited from both eastern and western sources, resulting in different stratigraphy for the eastern and western portions of the province.

The San Joaquin basin is an important hydrocarbon province. The southern part of the basin mainly produces oil and associated/dissolved gas. Nearly all this production is from Miocene and younger rocks. The northern part of the basin is an area of mostly nonassociated natural gas production.

P-650, SAN JOAQUIN BASIN
Generalized Stratigraphic Section

AGE	FORMATION	
	NORTH & WEST	EAST
Cenozoic		
Pleistocene	* Tulare Fm.	
Pleistocene-Pliocene		Kern River Fm.
Pliocene	* San Joaquin Fm.	
Miocene-Pliocene	* Etchegoin Fm.	Etchegoin Fm.
Miocene		Macoma Claystone Mbr.
		Lerdo-Fairhaven sand
	Reef Ridge Fm.	Chanac Fm.
	* Santa Margarita-	U. Fruitvale Sh.-Stevens Ss. Mbr.
	* McLure Fm.	"Pulv Zone" sand bed
		L. Fruitvale Sh.
	Kettleman sand bed	
	* Big Blue-U. Temblor Fm.	Temblor Fm.-
		* Round Mt. Silt Mbr.
	* L. Temblor Fm.	* Freeman Jewett Silt
		Rio Bravo sand bed
Miocene-Oligocene		* Vedder Sand
	* Burbank Sand	
Oligocene	Whereley Sh.	
	* Vaqueros Ss.	
	Leda sand bed	
Eocene	Wagon Wheel-Tumey Fm.	Tumey Fm.
	* Kreyenhagen Sh.	* Kreyenhagen Fm.
	Domengine-	
	* U. McAdams Ss.	
	Getchell-	
	* L. McAdams Ss.	
	* Lodo Fm.	
	Arroyo Hondo Sh. Mbr.	
	Cantua Ss. Mbr.	
Paleocene	Cerros Sh. Mbr.	
	San Carlos sand bed	
	* Moreno Fm.-	
Mesozoic	Dos Palos Sh. Mbr.	
Cretaceous	* Moreno Fm.	
Late	* Panoche Gp.	
	Brown Mountain Ss. Mbr.	
	Ragged Valley Silt	
	Joaquin Ridge Ss. Mbr.	
	Alcalde Sh.	
	Los Gatos Ss. Mbr.	
	Waltham Canyon Fm.	
Early	Long Canyon Ss.	
	Oak Flat Fm.-Curry Mt. Sh.	
	Dowdle Ss. Mbr.	
	Springs Road Ss.	
	Center Peak Cgl. Mbr.	
	Fresno Springs Canyon Sh.	
	Gravelly Flat Fm.	
	Wisenor Fm.	
Jurassic(?)	Franciscan Subduction Complex	

* Currently producing

The flanks of the San Joaquin basin have been tested by thousands of wells. Most of these wells are shallow (less than 5,000 feet). Many wells in the basin have been drilled to depths between 10-15,000 feet along the basin margin and within the central basin. Depths greater than 15,000 feet have been tested only rarely. However, no significant encouragement at depths below 15,000 feet in the San Joaquin basin has been seen to date.

The Probable resources are likely to be found in field extensions and infill drilling. Possible resources are expected to be found in associated gas fields ranging in size from 0.25 to 100 Bcf. Most fields will average 1 to 12 Bcf of gas. Speculative resources are expected to be found in associated gas fields ranging in size from 10 to 150 Bcf, with the average ranging from 10 to 20 Bcf.

Reservoir rocks. Nearly all reservoir rocks in the basin are sandstones. These range in age from Late Cretaceous to Pleistocene. Included are the Upper Cretaceous to Tertiary Moreno Formation and numerous Tertiary and Pleistocene units. Some production is from Miocene fractured shale and from fractured basement schist.

Traps. All producing fields in the basin involve more than one trapping style. Anticlines and faulted anticlines are common and may be combined with one or more stratigraphic mechanisms. Common stratigraphic traps include sandstone pinch outs, truncations and diagenetically altered permeability.

Source rocks. Most of the shales in the basin are sapropelic. All are mature and are probable source rocks.

Trends. Producing trends in the province are the Bakersfield arch, West Side, East Side, Central Valley, South End Overthrust area, Paloma Deep production and the Northern Gas Province.

P-660, CALIFORNIA COASTAL BASINS

This province is made up of the Coast Ranges, Transverse Ranges and six small basins. Large quantities of oil, associated/dissolved and nonassociated gas are produced in this province. Most production occurs in the southern basins.

The Los Angeles basin is a triangular region about 70 miles long and 40 miles wide and extends offshore. It covers approximately 1,450 square miles and is bounded on the north by the San Gabriel Mountains, on the southeast by the Santa Ana Mountains and on the south by other parts of the Peninsular Ranges. More than 31,000 feet of Miocene and younger sedimentary rocks fill the deeper parts of the basin. Most of the basin is covered by Pleistocene alluvial deposits. Basin deformation began in the Miocene and culminated in the middle Pleistocene. Major faults and folds trend northwesterly across the basin.

The Ventura basin is a long eastward-trending re-entrant. It is bounded by two of the Transverse Ranges. Most of this basin is offshore. Compressional forces have formed east-trending anticlines and thrust faults in the basin. As much as 55,000 feet of sedimentary rocks were deposited within the onshore portion of this basin.

The Santa Maria basin is a wedge-shaped re-entrant in the Coast Ranges. Sedimentary rocks are confined to 30 miles onshore but extend offshore. East-trending elongate folds cross the region.

The Santa Cruz basin is a wedge-shaped coastal basin. It covers approximately 260 square miles. It is bounded on the north and east by the San Andreas fault, and Franciscan basement rocks crop out on the south by Monterey Bay

P-660, CALIFORNIA COASTAL BASINS
Generalized Stratigraphic Section

AGE	FORMATION		
	LOS ANGELES BASIN	VENTURA BASIN	SANTA MARIA BASIN
Cenozoic			
Pleistocene	San Pedro Fm.- La Habra Fm.	San Pedro Fm.- Saugus Fm. Santa Barbara Fm.	Orcutt Fm. Paso Robles Fm.- Santa Barbara Fm.
Plio-Pleist.	Fernando Fm.- San Diego Fm.		
Pliocene	* Repetto Fm.	* Pico Fm.- Sunshine Ranch Fm.	Careaga Ss.-Morales- * Foxen Muds
Mio-Pliocene	Capistrano Fm.- Olay Fm.	Ridge Basin Gp.- Towsley Fm.	* Sisquoc Fm.
Miocene	* Puenta Fm.- Monterey Fm. "Santa Margarita" San Onofre Breccia * Topanga Fm.	Monterey- Castaic- Mint Canyon- * Modelo Fm. Topanga Fm. Tick Canyon Fm.	Santa Margarita Fm.- * Monterey Fm. * Point Sal Fm. Lopse Fm.- * Rincon Sh.
Olig.-Miocene	Vaqueros Fm.	* Vaqueros Fm.- Vasquez Fm.	Vaqueros Fm.
Oligocene			Simmler-Alegria-Sespe Fm.
Olig.-Eocene	Sespe Fm.	* Sespe Fm.	
Eocene	Santiago Fm.- Poway Gp.- La Jolla Gp. Matilija Fm.	* Coldwater Ss. Cozy Dell Sh.- * Llajas Fm. Matilija Fm. Santa Susana Fm.	Sacate Fm. Cozy Dell Sh.
Paleo.-Eocene			Pattiway Fm.-Anita Fm.
Paleocene	Silverado Fm.	"Martinez" Fm.- Coal Canyon Fm.	
Mesozoic			
Cretaceous			
Late	Rosario Gp.-Williams- Ladd-Lusardi Fm. Trabuco Fm.	Chatsworth Fm.- Tuna Canyon Fm.	Jalama Fm.
Early	(missing)	(missing)	Espada Fm.
Jurassic			* Knoxville Fm. & Franciscan rocks

* Currently producing

The Salinas-Cuyama basin is an elongate, northwest-trending onshore basin. It is about 160 miles long and 28 miles wide and covers 3,100 square miles. It is bounded on the southwest by the Nacimiento fault zone and on the northeast by the San Andreas fault zone. It contains more than 15,000 feet of Tertiary sedimentary rocks.

The Humboldt, or Eel River, basin is in northwestern California. It is triangular in shape and covers 575 square miles. It is bounded on the northeast and south by upthrown basement rocks. It contains more than 12,000 feet of Miocene and younger rocks. Basin deformation occurred during the Pleistocene.

Reservoir rocks. The reservoir rocks in the Los Angeles basin are the Pliocene Pico and Repetto Formations; the Miocene Puente and Topango Formations and the fractured Jurassic Catalina Schist. Of these, the Repetto Formation is the most prolific. Reservoir rocks in the Ventura basin are the Pliocene Pico and Repetto Formations; the Miocene Rincon Claystone and Vaqueros Formation; the Eocene-Oligocene Sespe Formation and the Eocene Coldwater Sandstone. Of these, the Pliocene and Miocene are the most prolific. In the Santa Maria basin, the reservoir rocks are the Pliocene Foxen and Sisquoc Formations; the Miocene Monterey Formation; the Oligocene-Miocene Point Sal and Lopse Formations and the Jurassic Knoxville Formation. Much of the production in this basin is from fractured reservoirs in chert, shale and tight sandstone. In the Salinas-Cuyama basin, the main reservoirs are the Miocene Dibble Sandstone and the Miocene Lombardi Sandstone. In the Santa Cruz basin, production is from Eocene sandstone. Probable reservoirs in the Humboldt basin are the Pliocene Scotia Bluff Sandstone, Rio Dell Formation and Eel River Formation and the Miocene Pullen Formation.

Traps. The major trapping mechanisms in the Los Angeles basin and Humboldt basin are anticlines, faults and faulted anticlines. These are important trap formers in the other basins as well. Other trapping mechanisms include sandstone lenses, truncations and porosity variations in the Santa Maria basin. Sandstone pinch outs occur in all basins. Onlapping sandstones form traps in the Salinas-Cuyama basin. Fracture porosity is important in the Los Angeles, Santa Maria and Ventura basins.

Source rocks. The Miocene Monterey is a likely source rock in the Ventura, Santa Maria and Salinas-Cuyama basins. The Miocene Rincon Claystone is a probable source rock in the Ventura basin. In the Los Angeles basin, the source rocks are the Pliocene Repetto Formation and the Miocene Puente and Modelo Formations. In the Humboldt basin, the probable source rocks are the Pliocene Rio Dell and Eel River Formations and the Miocene Pullen Formation.

P-960 AND P-961, PACIFIC OFFSHORE, SHELF AND SLOPE

Many of the coastal deposits extend offshore and are especially important in the southern California regions. The Los Angeles, Ventura and Santa Maria basins all extend offshore, and all present offshore production is confined to these extensions. Offshore southern California is composed of numerous horsts and grabens, and as much as 58,000 feet of sedimentary rocks lie in the offshore Ventura basin. The southern California region has good potential for future resource development. Although there is presently no production in offshore Washington or Oregon, the shelf is 30 to 40 miles wide and has potential for future development.

Reservoir rocks. Reservoir rocks in the California Offshore area include both sandstone and fractured shale. These range in age from Eocene to Pliocene. Included are the Eocene Sacate and Cozy Dell, the Oligocene Sespe, Alegria and Gaviota, the Miocene Vaqueros, Rincon, Monterey fractured shales and Puente and the Pliocene Repetto and Pico.

Traps. All producing fields involve faulted anticlines. Stratigraphic mechanisms such as truncations, sandstone pinch outs and diagenetically altered permeability also affect production.

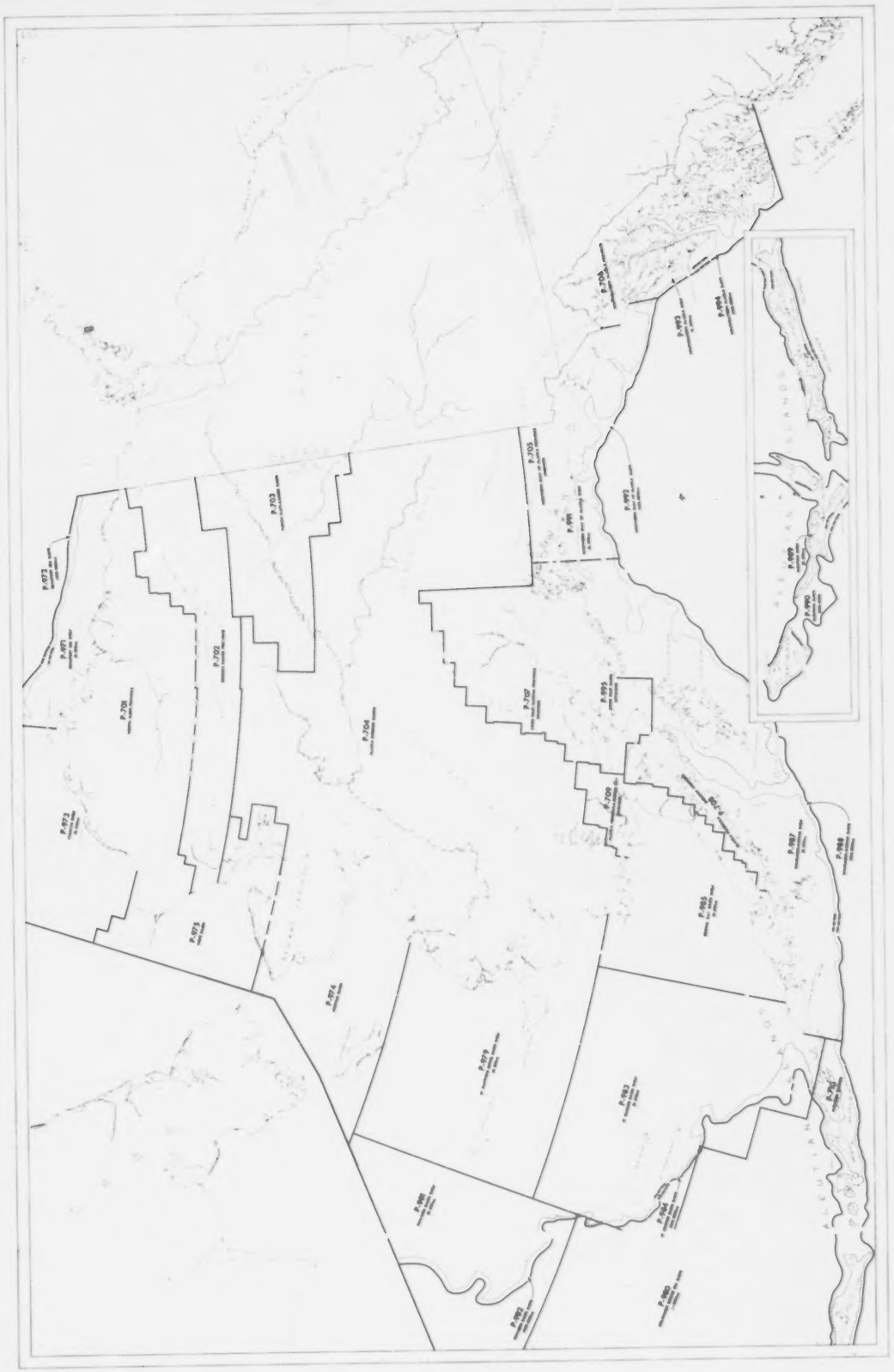
Source rocks. Pliocene shale, the Miocene Monterey Formation and the Miocene Rincon Claystone are probable sources of most of the hydrocarbons.

Table 14. Estimated resources of natural gas for provinces of the Pacific Area, December 1990 (billion cubic feet)

PROVINCE	PROBABLE			POSSIBLE			SPECULATIVE		
	Min.	M. likely	Max.	Min.	M. likely	Max.	Min.	M. likely	Max.
Onshore, less than 15,000'									
P-600, Oregon-Washington coastal basins, Okanogan	20	50	100	300	1,000	2,000	*	1,700	5,000
P-610, Eastern Columbia Basin							*	1,000	3,000
P-620, Great Basin-Southern Oregon							*	700	2,000
P-630, Southeastern California basins							*	500	1,000
P-640, Sacramento basin	300	600	1,100	700	1,600	3,300	*	1,500	5,000
P-650, San Joaquin basin	150	250	500	500	1,000	1,500	300	1,000	2,000
P-660, California coastal basins	200	300	500	500	1,000	2,000	200	600	1,300
Onshore, 15,000-30,000'									
P-600, Oregon-Washington coastal basins, Okanogan							*	*	2,000
P-610, Eastern Columbia Basin							*	*	2,000
P-620, Great Basin-Southern Oregon							*	*	1,000
P-630, Southeastern California basins							*	*	*
P-640, Sacramento basin							*	*	*
P-650, San Joaquin basin				*	150	1,000	*	100	1,500
P-660, California coastal basins	200	200	300	400	600	1,200	100	400	800
Offshore, 0-200 m									
P-960, Pacific shelf	35	55	80	3,100	5,200	8,300	900	1,800	3,000
Offshore, 200-1,000 m									
P-961, Pacific slope	45	65	100	2,800	4,700	7,500	2,100	4,100	7,000
Sum of Most Likely Estimates									
Onshore, 0-15,000'		1,200			4,600			7,000	
Onshore, 15,000 - 30,000'		200			750			500	
Onshore, All Depths		1,400			5,350			7,500	
Offshore, 0 - 200 m		55			5,200			1,800	
Offshore 200 - 1000 m		65			4,700			4,100	
Offshore, All Depths		120			9,900			5,900	
GRAND TOTAL FOR AREA		1,520			15,250			13,400	

*Negligible quantity of natural gas estimated.

Mean values by statistical aggregation	Probable Mean	Possible Mean	Speculative Mean
	1,717	16,783	17,867



ALASKA AREA

While the principal emphasis of exploration in Alaska centers on the North Slope, drilling activity has now begun in the frontier basin of the Chukchi Sea, with work completed on three wildcat wells, and preparations made for several others. Permitting problems have continued to plague operators, but activity is expected to increase somewhat over the next few years as this new basin is evaluated by the drill bit. No changes in reserve figures are yet warranted for the Chukchi at this time.

Cook Inlet has also experienced an increase in activity, with an increase in seismic evaluation and the drilling of several new prospects. Again, no announced discoveries have yet been made, but the industry is in the early phases of a several-years program of activity.

The North Slope saw the discovery of a new oil field at Point McIntyre, which is estimated at this preliminary date to contain at least 300 million barrels of oil. Delineation drilling continued through 1990 in this new field. While gas reserves will eventually be affected by this discovery, no significant change is yet warranted due to the lack of present markets for the gas.

Significant progress was made, however, in the planning and preparation for the Trans Alaska Gas System (gas pipeline) to be constructed during the mid to late 1990s from the North Slope to Valdez. Rights-of-way permits, an approved environmental impact statement, an export permit, commitments to supply gas, and letters of intent from the Korean government to purchase gas show the progress and sincerity of the companies involved. More commitments from the marketing end are still necessary to bring this large project to fruition.

After suspension of the State of Alaska oil and gas lease sale program in June 1989, in the wake of the Prince William Sound oil spill, the State resumed its leasing program in January 1991. Sales were held for tracts in the Kuparuk Uplands of the North Slope and in the upper Cook Inlet. Leasing activity is now expected to continue at regular intervals in the future for both state and federal acreage.

P-701, ALASKA NORTH SLOPE

The Alaska North Slope geologic province includes a total of 54,610 square miles and extends from the Beaufort Sea in the north to the Brooks Range in the south. The majority of Alaska's oil production currently comes from this area and is concentrated along the Barrow arch trend. Although the province contains significantly large reserves of natural gas there is no current gas production due to lack of pipeline facilities and a poor economic climate.

Reservoir rocks. Deposition along the Barrow arch took place in a linear, downfaulted basin located along a stable, passive cratonic margin. Potential reservoir rocks consist largely of Mississippian to Tertiary clastic rocks deposited in this basin. Current production comes from the Ellesmerian sequence of rocks, ranging in age from Mississippian to earliest Cretaceous, and from the Brookian sequence, ranging in age from Early Cretaceous to Tertiary. Principal sandstone reservoirs include the Permo-Triassic Sadlerochit Group (oil and gas), Triassic Sag River Formation (oil and gas), Lower Cretaceous Kuparuk River Formation (oil and gas), sandstones of the Lower Cretaceous Nanushuk Group (oil and gas), sandstones of the Upper Cretaceous Colville Group (oil), Upper Cretaceous West Sak sands (oil), and Tertiary Sagavanirktok Formation (gas). Carbonate reservoirs include the Mississippian-Pennsylvanian Lisburne Group (oil) and the Triassic Shublik Formation (oil and gas).

Traps. Accumulations in the Ellesmerian sequence are trapped by combinations of folding, faulting, and truncation by a major unconformity at the base of the Brookian sequence (Lower Cretaceous unconformity). Seals are generally provided by overlying shale or other less permeable rocks. Brookian sequence hydrocarbon accumulations appear to be due primarily to stratigraphic changes. Permafrost is believed to be a trapping mechanism for gas accumulations in the younger Brookian sequence.

P-701, ALASKA NORTH SLOPE
Generalized Stratigraphic Section

AGE	FORMATION
Cenozoic	
Quaternary	Gubik Fm.
Tertiary	Brookian sequence
	† Sagavanirktok Fm.
	† Flaxman Island sands
	† Ugnu Fm./Point Thomson sands
Mesozoic	
Cretaceous	
Late	Colville Gp.
	Prince Creek Fm.
	† West Sak sands
	Seabee Fm.
Early	† Nanushuk Gp./unnamed shale
	Okpikruak Fm.
	* Ellesmerian sequence
	* Kuparuk River Fm./Kemik Ss.
Jurassic	* Kingak Sh.
Triassic	* Karen Creek Ss./Sag River Fm.
	* Shublik Fm.
	* Sadlerochit Gp. (Ivishak Ss.)
Paleozoic	
Permian	
Pennsylvanian	* Lisburne Gp.
Mississippian	* Endicott Gp. (Kekiktuk Fm.)
Pre-Mississippian	Franklinian Sequence

* Currently producing
† Potentially productive

Potential source rocks. Shales contained in Mississippian, Permian, Jurassic, Cretaceous and Tertiary sequences are the most likely source rocks for the hydrocarbon accumulations.

Future exploration. Based on the successful exploration efforts to date, the main exploratory interest in Alaska remains in the North Slope province and the adjacent Beaufort Sea province.

P-702, ALASKA SOUTHERN FOOTHILLS AND BROOKS RANGE

This province encompasses the Brooks Range from the foothills in the north to the Koyukuk, Yukon Flats and Kandik basins, which form the southern border. The area of the entire province totals 65,373 square miles. Tectonically the province has been classified as a deformed cratonic margin associated with strong folding and overthrusting.

No oil or gas fields or producing trends have been established in this province to date. However, the occurrence of bitumen, solid hydrocarbons and oil shale (tasmanite) of Early Cretaceous age have been reported.

Reservoir rocks. Potential reservoir rocks range from Devonian reef carbonates of the Hunt Fork-Beaucoup Formation to the Cretaceous Torok Shale. Other potential reservoir rocks are included in the Endicott Group (Devonian-Mississippian), the Skajit Formation (Silurian-Devonian), Lisburne Group (Mississippian-Pennsylvanian), Shublik Formation (Triassic), and Fortress Mountain Formation (Lower Cretaceous).

Traps. Prospective traps are considered to be related to thrust faults and faulted anticlines.

Potential source rocks. Shale and carbonate rocks, ranging in age from Devonian to Cretaceous are considered potential sources of hydrocarbons. These formations include Kayak Shale (Mississippian), "Kavik" Formation (Mississippian), Kingak Shale (Jurassic), and "pebble shale" (Lower Cretaceous).

P-703, YUKON FLATS BASIN AND KANDIK BASIN

This province includes a surface area of over 30,000 square miles and is divided into the Kandik basin and the Yukon Flats basin. Both basins are considered intermontane with sedimentary sections possibly exceeding 20,000 feet. The one exploratory well in the Kandik basin encountered tectonically repeated overly mature Mesozoic rocks. The two exploratory wells in the Yukon Flats basin were drilled in the extreme northeast margin and encountered thermally mature Paleozoic rocks at total depth. Although only three wells have been drilled in this province, the prospect for gas production appears small.

P-704, ALASKA INTERIOR BASINS

This province stretches over nearly 260,000 square miles from the southern foothills of the Brooks Range in the north to the Alaska Range and the Chugach Mountains in the south. It is bordered on the west by the Bering Sea and on the east by the Canadian border. Several sedimentary basins are included in the province: Bethel basin, Inoko basin, Lower Tanana basin, Holitna basin, Yukon delta (onshore portion of Norton basin), Minchumina basin, Middle Tanana basin and Copper River basin. No production of oil or gas has been established in this province. However, the Bethel basin, Copper River basin, Minchumina basin, and Holitna basin are thought to have some potential for future natural gas production.

The southeastern basins generally contain Tertiary rocks overlying Precambrian basement. Generally, the shallow intermontane Minchumina and Middle Tanana basins contain nonmarine molasse sediments that are thermally immature. Apart from coaly and carbonaceous material, the organic carbon content is low.

The northwestern portion of the province includes a thin Tertiary section that is probably thermally mature but contains a low organic carbon content. The Cretaceous section is thermally overmature. No shows have been reported in wells drilled to date.

The Copper River basin is a topographic basin floored with unconsolidated deposits of Quaternary age. In at least two localities in the south-central part of the basin, flammable methane gas is associated with saline springs seeps through the Quaternary sediments. Mesozoic sediments crop out along the periphery of the basin. Exposures indicate a thick section of both Upper and Lower Cretaceous rocks underlain by a thinner sequence of Jurassic rocks, which in turn are underlain by a series of Upper Triassic sedimentary rocks. Both the Jurassic and Cretaceous rocks are of marine origin and contain potential source rocks, in the form of organic shales, and potential reservoir sandstones. Triassic carbonates are also considered potential reservoirs. Wells drilled to date in the Copper River basin have encountered minor gas shows.

P-705, NORTHERN GULF OF ALASKA (ONSHORE)

This province encompasses approximately 15,000 square miles. It is bordered on the north by the Chugach Mountains, on the south by the Gulf of Alaska and on the east by the Canadian border. The major tectonic elements include the Yakataga and Yakatat basins. Nearly all rocks are of Tertiary age and consist almost entirely of detrital units. Prospective reservoir rocks range in age from Eocene to Miocene.

Oil production has occurred in the Katalla trend, on the shore of the Gulf of Alaska east of Cordova, which is the only established production in southern Alaska outside the Cook Inlet area. Oil and gas seeps were discovered in the Katalla area about 1896, and the first successful well was drilled in 1902. A small refinery was built in 1911, but it burned down in 1933 and there has been no production at Katalla since then. About 36 wells were drilled, all comparatively shallow, from 550 to 750 feet in depth. Total oil produced from the field was about 154,000 barrels. Later onshore exploratory wells in the province have encountered minor oil and gas shows.

P-706, SOUTHEASTERN ALASKA

This province is bordered on the north, south and east by the Canadian border and by the Pacific Ocean on the west. It covers a total area of about 31,000 square miles. No oil or gas production has been established in the province to date. Most rocks in the province have undergone intense deformation so that it is difficult to assess their petroleum potential, if any. Predominantly they consist of metamorphic and crystalline rocks.

P-707, COOK INLET—SUSITNA PROVINCE (ONSHORE)

This province encompasses a total area of 45,568 square miles. The province is bounded on the north and west by the Alaska Range and by the Chugach Mountains and Cook Inlet on the south. The major tectonic elements include the Susitna basin, Matanuska Valley, Cook Inlet basin and Augustine-Sedovia arch. Producing trends established to date are the Sterling/Beluga trend and the Hemlock/Tyonek/West Foreland trend. A few oil and gas seeps, as well as subsurface shows, have been reported. Several gas fields and two oil fields are on production from this province.

Reservoir rocks. All prospective intervals consist of detrital rocks, mainly sandstone, and mainly of Tertiary age.

Traps. Both structural and stratigraphic traps occur at all reservoir levels. All production thus far is from anticlines and faulted anticlines. Caprocks include the Kenai Group siltstone (Oligocene-Pliocene) and the siltstone unit of the West Foreland Formation (Paleocene).

Potential source rocks. The Tertiary Kenai Group shale and claystone are considered potential source rocks for gas. The Middle Jurassic Naknek Formation is considered capable of generating both oil and gas.

P-707, COOK INLET–SUSITNA PROVINCE (ONSHORE);
P-995, COOK INLET BASIN (OFFSHORE)
Generalized Stratigraphic Section

AGE	FORMATION
Cenozoic	
Tertiary	Kenai Gp.
	* Sterling Fm.
	* Beluga River Fm.
	* Tyonek Fm.
	* Hemlock Fm.
	* West Foreland Fm.
	Chickaloon Fm.
Mesozoic	
Cretaceous	Kaguyak Fm.
	Matanuska Fm.
	unnamed
	Herendeen Ls.
Jurassic	Naknek Fm.
	Chinitna Fm.
	† Tuxedni Gp.
	Talkeetna Fm.
Triassic	Kamishak Fm.

* Currently producing
† Potentially productive

P-708, ALASKA PENINSULA—SHELIKOF PROVINCE (ONSHORE)

This province encompasses a total area of 12,777 square miles. It is bordered on the north and west by the Aleutian Range and on the southeast by the Shelikof Strait. The major tectonic elements include the Wide Bay and Chignik anticlines and the Pearl Creek dome. The major stratigraphic units range in age from Triassic to Tertiary. Sandstone and conglomerate units form all reported potential reservoirs. No oil or gas production has been established in the province, although several wells reported oil shows.

P-709, ALASKA PENINSULA—BRISTOL BAY (ONSHORE)

This province includes 22,187 square miles in southwestern Alaska. No production has been established, but potential for oil and both associated/dissolved and nonassociated gas is envisaged. The region is bordered by the Aleutian Range on the southeast and by Bristol Bay on the northwest. Sedimentary rocks range in age from Jurassic to Pliocene, and potential source and reservoir rocks exist throughout the section. Sandstones are the dominant lithology. A variety of structural and stratigraphic traps may exist. Wells drilled in the province have encountered minor oil and gas shows. A gas test well drilled in the Becharof area was abandoned as dry in 1985.

P-710, ALEUTIAN ISLANDS

This province includes the land area of the Aleutian Islands. It is located to the southwest of the Alaska Peninsula and encompasses a large number of mainly volcanic islands. The volcanic nature of the islands suggests negligible potential for natural gas.

P-971 AND P-972, BEAUFORT SEA SHELF AND SLOPE

These provinces cover a total area of approximately 40,000 square miles. The first commercial oil and gas field on the Beaufort Shelf is now being developed just north of the Sagavinirktok delta and just northeast of the Prudhoe Bay field. Three other discoveries north and west from the Kuparuk delta are judged to be subcommercial with currently depressed oil prices, but optimism remains that major oil and gas reserves will be produced from the Beaufort Shelf region. No estimate has been made for potential that might exist below the continental slope at water depths from 200-1,000 meters because this area lies below the polar ice pack.

Reservoir rocks. Potential reservoir rocks are similar to the section in the adjacent onshore areas of the North Slope. The stratigraphic section contains rocks that range in age from Mississippian to Tertiary and are dominantly clastic rocks with the exception of Mississippian carbonates. Most of the prospective reservoir rocks occur in the Permo-Triassic section, but there are also some prospects in the Tertiary section to the east.

Traps. Stratigraphic traps are believed to be abundant. They include pinch outs (in Tertiary and Cretaceous units), truncations (Jurassic and Triassic rocks), and onlap in the Mississippian sequence. Structural traps are also postulated related to both folding and faulting.

Potential source rocks. Potential source rocks for both oil and gas exist in the Mississippian to Lower Cretaceous sequence and in Upper Cretaceous-Tertiary rocks. The rocks range from thermally immature to very mature.

Future exploration. Most of the exploration plays to date consist of extensions of onshore trends. The difficulties of interpretation are exemplified by recent dry holes. The enormous potential of the adjacent onshore area and the likelihood of extensions of similar conditions into the offshore area are stimulants to continued exploration in spite of high costs and difficult conditions.

P-973, CHUKCHI SHELF

This province covers an area of approximately 61,000 square miles. No oil or gas production has been established to date. Potential reservoir rocks range in age from Mississippian to Tertiary. The rocks are predominantly clastic, although prospective reservoirs in Mississippian-age rocks are limestones and dolomites. Both stratigraphic and structural traps are anticipated. There has been no exploratory drilling to date in this province.

P-974, NORTON BASIN

This province covers an area of over 43,000 square miles. No oil or gas production has been established to date despite the drilling of six exploratory wells during 1984 and 1985. Prospective reservoir rocks range in age from Cretaceous to Tertiary and consist mainly of sandstone. Stratigraphic and structural traps are anticipated and have been noted in Tertiary rocks. Gas seeps, rich in carbon dioxide, have been reported from the area.

P-975, HOPE BASIN

This province is dominantly an offshore area, including mainly Kotzebue Sound and parts of the Bering Strait, but it also extends onshore to include a small area of the Seward Peninsula. Sedimentary rocks in the area range in age from Cretaceous to Tertiary. No natural gas or oil production has been established in the province.

The onshore portion is considered to have low potential for natural gas production. It contains a thin section of thermally immature, nonmarine Tertiary sandstone, conglomerate and shale. The offshore portion has a thicker sedimentary section and is considered to have some potential from rocks of Cretaceous and Tertiary age. Both structural and stratigraphic traps may exist. Potential source rocks are primarily of Tertiary age.

P-979, ST. MATTHEW BASIN-BETHEL BASIN SHELF

This province includes an area of more than 91,000 square miles. No oil or natural gas production has been established, and the province is not considered to have potential for future natural gas production primarily due to a thin section of thermally immature rocks.

P-980, SOUTHWEST BERING SEA SLOPE

Water depths in this province are all greater than 1,000 meters. No estimate of natural gas potential has been made at this time.

P-981 AND P-982, NAVARIN BASIN, SHELF AND SLOPE

These provinces include an area of approximately 49,000 square miles covered by water depths of less than 1,000 meters. Sedimentary rocks range in age from Jurassic to Tertiary, and detrital units predominate. No production of natural gas or oil has been established in these provinces to date despite the drilling of nine exploratory wells during 1985. Potential reservoir rocks are of Jurassic, Cretaceous and Tertiary age. Both stratigraphic and structural traps are believed to occur. Pinch outs generally occur in Tertiary strata, whereas truncations and onlap are associated with Mesozoic rocks. Anticlines and faulted anticlines are common in Mesozoic as well as Tertiary units. Growth faults and draping also occur in the Tertiary section. Potential source rocks probably exist in the Jurassic, Cretaceous and lower Tertiary sections.

P-983 AND P-984, ST. GEORGE BASIN, SHELF AND SLOPE

These provinces encompass an area of approximately 96,000 square miles. No oil or gas production has been established to date despite the drilling of nine exploratory wells during 1984 and 1985. Sedimentary rocks in the provinces are predominantly detrital and range in age from Jurassic to Tertiary. Potential reservoir rocks in the shelf province consist of sandstones of Jurassic, Cretaceous and Tertiary age. In the slope province, potential reservoirs for oil and gas are Paleogene (lower Tertiary) turbidites.

P-985, BRISTOL BAY BASIN SHELF

Approximately 55,000 square miles are included in this province, which is all covered by water depths of less than 200 meters. Sedimentary rocks are generally detrital and range in age from Jurassic to Tertiary. No natural gas or oil production has been established to date. Potential reservoir rocks are sandstones of Jurassic, Cretaceous and Tertiary age. Both stratigraphic and structural traps occur. Truncations are most common in Mesozoic strata, whereas onlap and pinch outs appear restricted to Tertiary units. Faulted anticlines and faults are common at all stratigraphic levels. Potential source rocks are mostly of Cretaceous and early Tertiary age, although Jurassic units may also be a possible source.

P-987 AND P-988, SHUMAGIN-KODIAK SHELF AND SLOPE

This area lies offshore from southern and southwestern Alaska and encompasses an area of over 80,000 square miles. Sedimentary rocks are Cretaceous and younger, but Tertiary detrital units predominate. No natural gas or oil production has been established in the province. Potential for natural gas production is believed to occur in rocks of Tertiary age, generally sandstone, in the Shelf area. Traps may be either structural or stratigraphic. Most potential source rocks are in the Tertiary section.

P-989 AND P-990, ALEUTIAN SHELF AND SLOPE

The Aleutian Shelf and Slope cover an area of almost 85,000 square miles. Most of the rocks are related to volcanic activity of the Aleutian Islands and to tectonism that formed the Aleutian Trench and the Islands. Most of the sedimentary rocks are of younger Tertiary age. No production of natural gas or oil has been established in the province, and the potential for future natural gas production is very low.

P-991, P-992, P-993 AND P-994, NORTHERN GULF OF ALASKA AND SOUTHEASTERN ALASKA SHELF AND SLOPE

These provinces have a combined area of approximately 56,000 square miles. Sedimentary rocks are predominantly of Tertiary age and are generally detrital. No production of natural gas or oil has been established. Potential reservoir rocks include Tertiary formations. Both structural and stratigraphic traps occur and include truncations and onlap as well as anticlines and faulted anticlines. Potential source rocks may occur within the early Tertiary section.

P-991, P-992, P-993, and P-994, NORTHERN GULF OF ALASKA AREA, SOUTHEASTERN ALASKA SHELF AND SLOPE
Generalized Stratigraphic Section

AGE	FORMATION
Cenozoic	
Tertiary	Tugidak Fm.
	† Yakataga Fm.
	Sitkinak Fm.-
	† Katalla Fm.
	† Poul Creek Fm.
	† Tokun Fm.
	Sitkalidak Fm.-Orca Gp.-
	† Kulthieth Fm.
	Ghost Rocks Fm.
Mesozoic	Kodiak Fm.-Valdez Gp.-
	Yakutat Gp.

† Potentially productive

P-995, COOK INLET BASIN-OFFSHORE

This province is the offshore portion of the Cook Inlet basin; the onshore portion is included in province P-707. It covers slightly more than 7,400 square miles. Sedimentary rocks in the province are predominantly detrital and range in age from Jurassic to Tertiary. This, and the adjoining onshore province, is the only area of current natural gas and oil production in Alaska outside of the North Slope. Two trends of natural gas production and two trends of oil production have been established.

Reservoir rocks. Sandstone and conglomerate of Tertiary age are the primary gas and oil reservoirs. The Tertiary Beluga and Sterling Sandstones are productive of gas only.

Traps. Sandstone pinch outs and anticlinal trapping are both common in the Tertiary section. Truncation by unconformities and faulted anticlines are common trapping mechanisms in Mesozoic reservoirs.

Potential source rocks. Thermally immature to mature Tertiary rocks are considered a fair source for oil. Upper Jurassic, thermally moderately mature to very mature, rocks are considered good sources for oil and possibly for gas.

Table 15. Estimated resources of natural gas for provinces of the Alaska Area, December 1990 (billion cubic feet)

PROVINCE	PROBABLE			POSSIBLE			SPECULATIVE		
	Min.	M. likely	Max.	Min.	M. likely	Max.	Min.	M. likely	Max.
Onshore, less than 15,000'									
P-701, North Slope province	26,600	30,600	36,600	4,000	15,000	43,000	6,000	23,000	72,000
P-702, Brooks Range province							*	*	1,000
P-703, Yukon Flats-Kandik basins							*	200	500
P-704, Alaska Interior basins							*	500	2,500
P-705, Northern Gulf of Alaska, onshore							100	700	3,550
P-706, Southeastern Alaska							*	*	*
P-707, Cook Inlet/Susitna province, onshore	400	650	1,600	700	1,400	2,800	*	2,400	4,800
P-708, Alaska Peninsula/ Shelikof province, onshore							*	200	300
P-709, Alaska Peninsula/Bristol Bay province, onshore							400	700	1,400
P-710, Aleutian Islands							*	*	1,000
Onshore, 15,000 - 30,000'									
P-701, North Slope province							NO RELIABLE DATA		
P-702, Brooks Range province							NO DATA		
P-703, Yukon Flats-Kandik basins							NO DATA		
P-704, Alaska Interior basins							NO DATA		
P-705, Northern Gulf of Alaska, onshore							NO RELIABLE DATA		
P-706, Southeastern Alaska							*	*	*
P-707, Cook Inlet/Susitna province, onshore							*	*	*
P-708, Alaska Peninsula/ Shelikof province, onshore							NO RELIABLE DATA		
P-709, Alaska Peninsula/Bristol Bay province, onshore							NO RELIABLE DATA		
P-710, Aleutian Islands							NO RELIABLE DATA		

*Negligible quantity of natural gas estimated.

Note: In addition to the Probable resource estimate of 6,000 Bcf for province P-701, North Slope province, reserves of approximately 24,600 Bcf have been demonstrated to exist in fields currently developed on the Alaskan North Slope according to estimates of the Committee on Natural Gas Reserves of the American Gas Association. Reserves of approximately 25,000 Bcf are included in reserve estimates published by the Energy Information Administration, U.S. Department of Energy. These reserves are not carried in estimates of proved reserves prepared by some companies and have been considered as additional Probable resources.

Table 15. Estimated resources of natural gas for provinces of the Alaska Area, December 1990 (billion cubic feet) (continued)

PROVINCE	PROBABLE			POSSIBLE			SPECULATIVE		
	Min.	M. likely	Max.	Min.	M. likely	Max.	Min.	M. likely	Max.
Offshore, 0-200 m									
P-971, Beaufort shelf	1,000	2,000	11,000	3,000	12,000	41,000	3,500	19,500	62,500
P-973, Chukchi shelf							3,500	19,500	62,500
P-974, Norton basin							*	200	600
P-975, Hope basin							*	550	2,000
P-979, St. Matthew shelf							*	*	*
P-981, Navarin basin shelf							*	1,000	4,000
P-983, St. George shelf							200	1,500	2,500
P-985, Bristol Bay shelf							1,850	3,750	6,000
P-987, Shumagin shelf							200	1,700	5,200
P-989, Aleutian shelf							*	*	1,000
P-991, N. Gulf Alaska shelf							100	800	2,400
P-993, SE Alaska shelf							200	850	2,600
P-995, Cook Inlet, offshore	200	400	800	350	700	1,400	*	1,000	2,400
Offshore, 200-1,000 m									
P-972, Beaufort slope							NOT ESTIMATED		
P-982, Navarin basin slope							*	*	500
P-984, St. George slope							*	*	500
P-988, Shumagin slope							NOT ESTIMATED		
P-990, Aleutian slope							*	*	*
P-992, N. Gulf Alaska slope							450	2,650	6,550
P-994, SE Alaska slope							NO DATA		
Offshore, >1,000 m									
P-980, Southwestern Bering Sea	NOT ESTIMATED - ALL WATER DEPTHS GREATER THAN 1,000 m								
Sum of Most Likely Estimates									
Onshore, 0-15,000'		31,250			16,400			27,700	
Onshore, 15,000 - 30,000'		*			*			*	
Onshore, All Depths		31,250			16,400			27,700	
Offshore, 0-200 m		2,400			12,700			50,350	
Offshore, 200-1,000 m		*			*			2,650	
Offshore, All Depths		2,400			12,700			53,000	
GRAND TOTAL FOR AREA		33,650			29,100			80,700	

*Negligible quantity of natural gas estimated.

Mean values by statistical aggregation	Probable Mean	Possible Mean	Speculative Mean
	37,288	41,816	115,129

NATURAL GAS RESOURCES FROM COAL SEAMS

DEFINITION OF COALBED METHANE

Methane is the major hydrocarbon gas constituent evolved from coal during the coalification process whereby peat material is slowly transformed by chemical reactions into coal. Coal can serve both as a source bed for gas that is now contained in adjacent porous and permeable reservoir rocks, especially sandstone, and as absorbed gas trapped within the coal itself. Therefore, the coal may be both a source and reservoir of gas. The gas contained in porous and permeable reservoir rocks, though sourced in coal, is included in the basic Potential Gas Committee Area estimates. The gas trapped in the coal is considered coalbed methane and is estimated separately.

PRODUCTION OF COALBED METHANE

Coalbed methane has now become an important source of pipeline-quality gas. Production of methane directly from coal seams is rapidly increasing. During August-September 1990, daily production of this rapidly-developing energy resource was nearly 525 MMcf per day. Cumulative production of coalbed methane from active fields in the United States now exceeds 330 Bcf, most of this having been produced in the past several years. The San Juan Basin of New Mexico-Colorado has produced more than 200 Bcf or 61 percent of the U.S. total; and the Black Warrior Basin, Alabama has produced more than 122 Bcf or 37 percent of the total. Based on preliminary information, approximately 200 Bcf of coalbed methane was produced in the United States during 1990 from nearly 2,500 wells. This is only two-thirds of the approximately 300 Bcf of methane that the U.S. Bureau of Mines estimates is being exhausted into the atmosphere from the required ventilation of gassy coal mines in the U.S.

In the near future, the San Juan basin is expected to be producing more than 700 MMcf/d from more than 1,000 Fruitland coalbed methane wells; annual production should exceed 170 Bcf in 1990. In contrast, in 1985, the basin produced only 2.1 Bcf from 64 wells.

Similarly, the annual production of coalbed methane in the Black Warrior basin in 1985 was only 8.65 Bcf from 55 wells; and nearly 17 Bcf in 1987 from 129 wells. In 1990, the basin was expected to produce more than 35 Bcf from more than 1400 wells.[1]

With a recent two-year extension of the IRS Code Section 29 tax credit (1984 Tax Reform Act), the high level of drilling for this "unconventional" fuel resource will result in coalbed methane completions comprising perhaps one-half of all gas wells drilled in the United States. High levels of activity in the proven productive basins — the San Juan and Black Warrior — are now spreading to coal-bearing areas in the Appalachian and Illinois basins and southeastern Kansas (Cherokee basin); and to the Powder River, Hanna and Wind River, Wyoming; Greater Green River, Wyoming-Colorado; Piceance and Raton, Colorado; Uinta, Utah; and Puget-Willamette, Washington, basins.

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[1] Petroleum Information Corp., Denver, CO.

According to the Energy Information Administration, U.S. Department of Energy, total proved reserves of coalbed methane in 1989 were 1.881 Tcf, with 0.461 Tcf having been added in 1989.[2]

Because of the growing importance of this energy supply, the Potential Gas Committee now includes estimates of recoverable coalbed methane in its reports. These estimates are presented separately reflecting the lack of data regarding production histories and recovery of in-place resources. Many prominent coal-bearing basins in the United States have yet to be evaluated for their coalbed methane potential. Reliable production histories spanning at least five to ten years exist in only a few coalbed methane fields or pools in the Black Warrior and San Juan basins.

The PGC Coalbed Methane Work Committee is divided into two regional subcommittees, Eastern and Western. As presently organized, the Eastern Region includes eleven distinct coal-bearing areas, comprised of basins, coal fields, coal deposits, coal occurrences, etc. The Western Region consists of 25 such areas, including the State of Alaska, which, at the present time is treated as one coal-bearing area, inasmuch as the coal resource evaluation still is in its early stages in that vast, incompletely explored state. According to the U.S. Geological Survey, as of 1983 at least 50 coal fields or occurrences have been identified in Alaska.

The work area boundaries, the aggregation of coal occurrences within each work area and the total quantity of coal-in-place determined by the Coalbed Methane Work Committee are, for the most part, based on the latest pertinent publication of the U.S. Geological Survey, *Coal Map of North America*.[3]

RESOURCE CATEGORIES

Three categories applicable to estimation of recoverable coalbed methane resources have been established. These categories are defined as follows:

Probable: Potential gas resources estimated to be recoverable in the future through extensions of areas of current development of coalbed methane resources. These resources do not include quantities currently estimated in proved reserves but occur under similar conditions and in close proximity to currently developed and tested reserves. Data are generally available for such factors as gas content of the coal, coal rank and production history, and are of good quality.

Possible: Potential gas resources estimated to be recoverable in the future from coal groups with established production and good data on gas content and rank of coal but from areas outside the areas of current development and production of coalbed methane resources.

Speculative: Potential gas resources estimated to be recoverable in the future from basins or coal groups with no established coalbed methane production. Data on gas content, rank of coal and similar characteristics are generally lacking or incomplete.

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[2] DOE/EIA-0216[89] Advance Summary, September, 1990.

[3] Wood, G.H., Jr. and Bour, W.V., III, 1988, Coal Map of North America: U.S. Geological Survey Special Geologic Map.

METHODS OF RESOURCE ESTIMATION

The determination of estimated gas in place is one of the key elements in estimating *recoverable* resources of coalbed methane. In those coal-bearing areas where there was a paucity of pertinent information, the U. S. Geological Survey map, *Coal Map of North America*, provided the logical starting place. Where appropriate, for the 32 coal-bearing areas studied, the total coal in place (onshore only) was determined by adding together the total coal-in-place for each of the coal occurrences comprising this area. The total coal in place estimated to be remaining below a depth of approximately 500 feet was then determined, allowing for the historic degree of mining in each area. Next, a range of in situ gas contents (in cubic feet per ton of coal) was estimated for each area, taking into consideration the rank(s) and depth range of the coal, available gas desorption data (if any), published correlations of gas content with depth (pressure) for the rank or range of ranks of the coals in question, and other pertinent information. An estimated range of recovery factors was then applied to the ranges of estimated gas in place for each area. In those areas for which a suitable analogue is not applicable, and in which no gas content or coal reservoir permeability data are available, where the coal rank is relatively low and depth of occurrence quite shallow, in situ gas contents of as low as 15 to 20 cf/ton and percent recovery from 20-30 percent were used. Some areas, such as the Fort Union coal region of North and South Dakota, and the Gulf Coast coal regions, which includes parts of Texas, Arkansas, Louisiana, Missouri, Kentucky, Tennessee, Mississippi, Alabama and Florida, contain lignite at or near the surface. However, in the subsurface, where this coal lies at depths between ±1,000 and ±6,000 feet in places, higher rank coals are known to be present, which increases their potential for commercial coalbed methane production. At the other extreme, basins with established production, such as the San Juan and Black Warrior, provide reliable analogues that may be used with some degree of confidence in coal-bearing basins possessing similar geologic and thermal histories, coal rank and other characteristics such as burial depth, hydrology, etc.

The key factor in such resource estimation, it should be stressed, is the judgment of the members of the Work Committee, strengthened by their knowledge and experience. Their use of the resource categories and estimates, ranging from minimum through most likely to maximum, reflects the range of uncertainties characterizing each estimate. The user is cautioned not to use a single recoverable resource number without acknowledging the range of possibilities and uncertainties. The "single answer syndrome" can be very misleading when dealing with the inherent risks and uncertainties involving estimates of recoverable resources, especially with a still somewhat "unconventional" energy resource such as coalbed methane, with its relatively brief production history and with as yet many unanswered questions regarding the present and ultimate performance of coalbed reservoirs.

RESOURCES OF COALBED METHANE

It should be emphasized that all the estimated coalbed methane resources contained in the present Potential Gas Committee tabulation represent the *recoverable* part of the estimated in-place resource calculated by the committee members in each of the areas evaluated. The 32 coal-bearing areas presently evaluated contain a total estimated in-place methane resource ranging from approximately 275 to 649 Tcf (depending on assumed average in situ gas content and other variables). Of this total in-place coalbed methane resource base, the Eastern Region contains between 73 and 184 Tcf, of which more than 50 percent is found in the Northern Appalachian plus "Black Warrior" basins. The Western Region has between 201 and 464 Tcf of in-place coalbed methane, of which more than one half occurs in the San Juan basin plus Alaska (five Alaska coal deposits only). Conservative recovery factors, varying from 20 to 50 percent of the estimated in situ gas contents, were applied in each instance. Furthermore, no attempt was made to estimate the volumes of the nonmethane components, including heavier gaseous hydrocarbons (C_2+), liquid hydrocarbons, and carbon dioxide, which can be generated by certain coals under specific conditions. More details are given for individual areas in the specific province discussions.

The 12/31/88 Potential Gas Committee report presented "estimated most likely recoverable resources" (with all three resource categories grouped together) of coalbed methane covering only five basins — the Appalachian (Northern and Central basins together), Black Warrior, Illinois, Piceance and San Juan (Fruitland Formation coals only) basins. In contrast, the present report lists the estimated recoverable supply (with minimum, most likely and maximum values for each of the probable, possible and speculative resource categories, where applicable), for each of 32 distinct coal-bearing areas, including some smaller occurrences, such as North and Middle Park coal fields, Colorado.

On the basis of the most recent information available, the PGC Coalbed Methane Work Committee, by the traditional method of summation of most likely estimates from each province, estimates the most likely recoverable resources of coalbed methane in the United States, including Alaska, to be 145 Tcf, as of 12/31/90. This figure is approximately 55 Tcf greater (61 percent increase) than the 90 Tcf estimated for the five areas treated in the PGC report as of 12/31/88. However, it should be emphasized that this latest report includes a total of 32 distinct coal-bearing areas. The latest estimates of potential supply of coalbed methane have been adjusted to reflect the shifting of approximately 13.5 Tcf from potential resources to proved reserves: 9.5 Tcf in the Black Warrior basin, Alabama; plus 4 Tcf in the San Juan basin, Colorado-New Mexico.

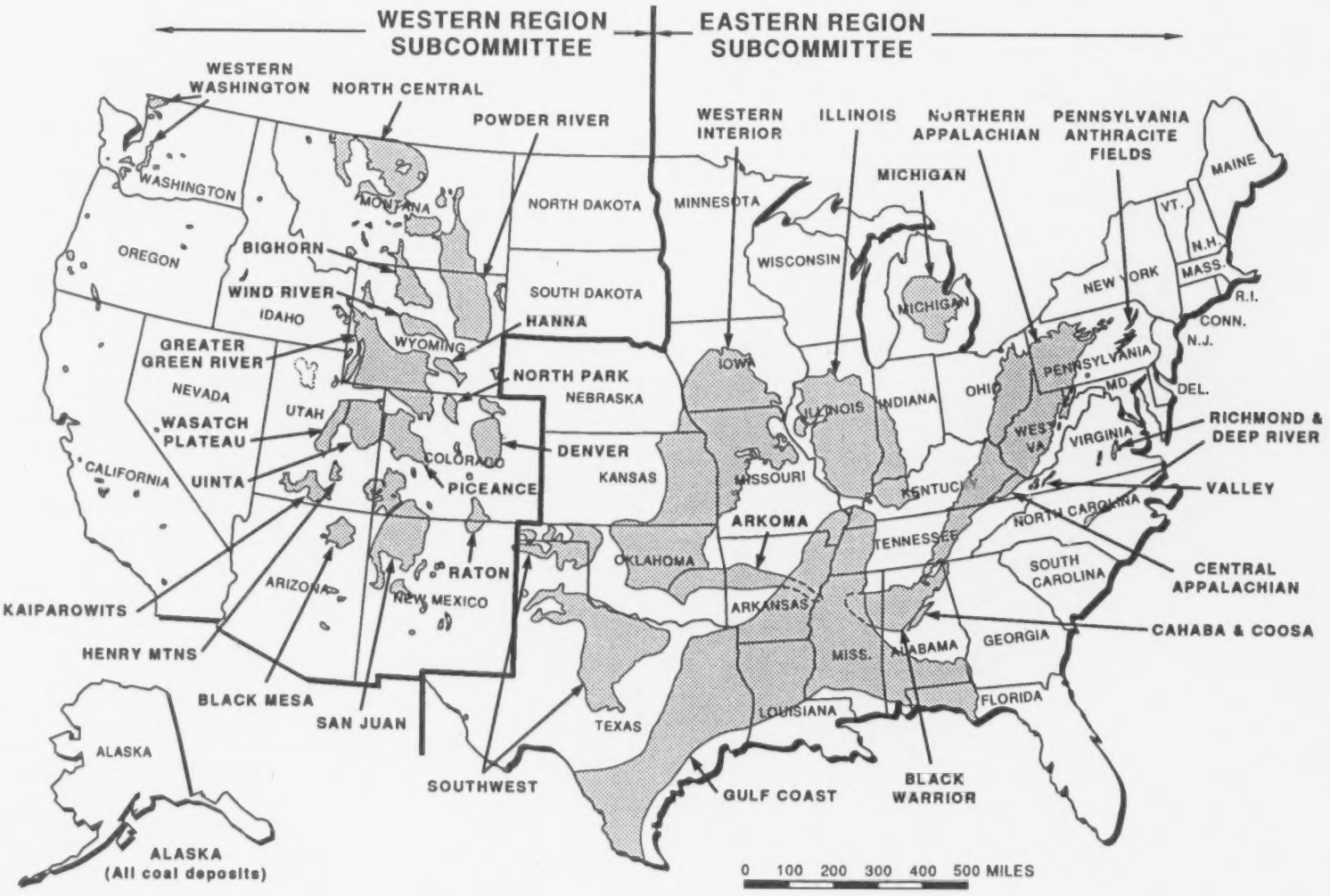

Figure 9. Coalbed Methane Resources of the United States

Table 16. Estimated coalbed methane resources, selected basins in conterminous United States, December 1990 (billion cubic feet)

PGC Region	Basin	State(s) included in evaluation	PROBABLE			POSSIBLE			SPECULATIVE		
			Min.	M. likely	Max.	Min.	M. likely	Max.	Min.	M. likely	Max.
Western	Powder River Coal Region	MT, WY	120	150	200	2,780	3,650	9,300			
	Fort Union Coal Region	ND, MT							25	500	875
	North Central Coal Region	MT							375	1,200	2,250
	Big Horn Basin Coal Region	MT, WY							560	1,050	2,520
	Wind River Basin Coal Region	WY							1,941	2,588	3,236
	Greater Green River Coal Basin (Hams Fork Coal Region, Sand Wash Basin)	CO, UT, WY				10	375	2,700	50	2,125	15,300
	Hanna-Carbon Basins (Hanna & Rock Creek Coal Fields)	WY							600	1,125	2,700
	Denver Basin Coal Region	CO							40	300	1,000
	North Park Basin (North & Middle Park Coal Fields)	CO							90	225	540
	Raton Basin (Raton Mesa Coal Region)	CO, NM	200	500	1,000	1,000	2,500	5,300			
	Piceance Basin (Eastern Uinta Coal Region)	CO	35	126	273	580	4,536	29,500			
	Tongue Mesa-Nucla-Naturita-Durango	CO, UT							500	2,250	5,000
	San Juan Basin (San Juan River Coal Region)	CO, NM	3,800	7,500	8,500	6,800	13,500	15,200			
	Uinta Basin-Book Cliffs Coal Field (Western Uinta Coal Region)	CO, UT				150	560	1,485	1,200	3,940	6,390
	Wasatch Plateau Coal Field (Western Uinta Coal Region)	UT							20	80	250
	Henry Mountains Coal Field	UT							5	15	30
	Kaiparowits Basin (SW Utah Coal Region, Kaiparowits Plateau, Alton & Kaibab Coal Fields)	UT							80	480	800
	Black Mesa Basin/Coal Region	AZ							40	180	480
	Western Washington (Puget-Willamette Basin, Pacific Coal Region)	WA							540	1,440	3,150
	Yakima Basin (Roslyn, Taneum, Manastash, Summit Creek Areas)	WA							140	525	1,225
	Matanuska, Chignik, Herendeen Bay, North Slope & Bering Riv Coal Fields	AK							14,250	57,000	95,000
	Sum of Most Likely Estimates Western Region			8,276			25,121			75,023	

Table 16. Estimated coalbed methane resources, selected basins in conterminous United States, December 1990 (billion cubic feet) (continued)

PGC Region	Basin	State(s) included in evaluation	PROBABLE			POSSIBLE			SPECULATIVE		
			Min.	M. likely	Max.	Min.	M. likely	Max.	Min.	M. likely	Max.
Eastern	Pennsylvania Anthracite Fields	PA							114	570	1,290
	Northern Appalachian Coal Basin	KY, MD, OH, PA, WV				2,050	10,000	22,050			
	Central Appalachian Coal Basin	KY, MD, TN, WV, VA				1,750	2,500	4,200			
	Atlantic Coast Coal Region	NC, SC, VA							72	180	360
	Black Warrior, Cahaba, Coosa and Plateau Coal Fields	AL, GA, MS	500	1,000	2,000	2,000	5,000	6,000	500	1,000	1,500
	Northern Coal Region	MI							10	60	125
	Eastern Interior Coal Region (Illinois Basin)	IL, IN, KY				1,200	2,137	5,512			
	Western Interior Coal Region (Cherokee Basin, SE Kansas)	IA, KS, MO, NE, OK	200	300	1,000	1,150	6,450	15,200			
	Arkoma Basin	AR, OK							336	1,750	4,620
	Southwestern Coal Region (Western OK-TX Panhandle Coal Fields)	OK, TX							600	2,400	3,750
	Gulf Coast Coal Region	AL, AR, FL, KY, LA, MO, MS, TN, TX							1,500	3,375	12,000
	Sum of Most Likely Estimates Eastern Region			1,300			26,087			9,335	

Sum of Most Likely Estimates Eastern and Western Regions	9,576	51,208	84,358

Mean values by statistical aggregation Eastern and Western Regions	**Probable Mean**	**Possible Mean**	**Speculative Mean**
	9,135	59,425	78,743

Appendix

Statistical Considerations in Handling Gas Resource Estimates

It is not statistically correct to add values of varying probability. This means that it is not proper to add most likely, minimum, and maximum estimates to arrive at Area and National totals. A simulation program is required to calculate the totals. The statistical aggregations of the gas resource estimates in this report were completed using commercially-available software, "@RISK," Version 1.00, distributed by the Palisade Corporation of Newfield, New York. The Microsoft Corporation "MS-Excel" spreadsheet program was used in conjunction with @RISK to input data and assist in analyzing the results.

The @RISK program employs simulation to derive a probability distribution of expected outcomes, based on the probability distributions of the input data. The program samples the specified input data distributions and recalculates the outcome a specified number of times (iterations). The output is a probability distribution of the results of each iteration. The sampling technique employed by the Potential Gas Committee is termed "Latin Hypercube." This technique is a relatively new sampling approach and is designed to more accurately recreate the distribution of input data, for a given number of iterations, than the Monte Carlo sampling method. Latin Hypercube employs a stratification approach to divide the cumulative probability distribution of the input data into equal intervals. A sample is then randomly taken from each interval or "stratification" of the input distribution. This sampling scheme forces the representation of the entire input distribution in the calculations, and therefore, should result in convergence of the output probability distributions, which are the aggregated gas resource estimates. Tests by the Potential Gas Committee indicate that Latin Hypercube sampling did converge faster, and result in more stable output distributions for a given number of iterations, than Monte Carlo sampling. A minimum of 1,000 iterations were used to aggregate Potential Gas Committee provinces into Area totals, and provincess into the National total. Triangular probability distribution functions were employed for the input probability functions, using the estimated minimum, most likely and maximum values provided by the appropriate PGC Area Work Committees and the Coalbed Methane Work Committee.

The @RISK program allows for consideration of dependency relationships between variables. While an independent variable is totally unaffected by any other variable within the model, a dependent variable is determined in whole or part, by some other variable within the model. The appropriate dependencies of PGC Areas were estimated and included in the simulation where applicable.

The Latin Hypercube sampling technique is usually employed only with fully independent variables, except, as in the case of the PGC estimates, where the dependence is specified and explicit correlation between variables is desired.

The statistical handling of the 1990 Estimates is also in accordance with the recommendations of the U.S. Energy Information Administration evaluation of domestic natural gas estimates (EIA, 1989)[1].

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[1] Energy Information Administration, 1989, An Examination of Domestic Natural Gas Resource Estimates: U.S. Department of Energy, Energy Information Administration [SR/RNGD/89-01], Washington, DC.

POLICY GUIDELINES

General Policy Statement

An appraisal of the long-range prospects of the natural gas industry in the United States—an appraisal that is useful for financial, managerial and government purposes—requires, as an essential element, scientific, authoritative, and objective estimation of the potential supply of natural gas that may become available to the nation in addition to currently available proved recoverable reserves of natural gas.

The Potential Gas Committee fulfills this requirement by providing periodic estimates of the potential supply of natural gas that may become available. The PGC, together with its several Area Work Committees d Coalbed Methane Work Committee, is composed of about one hundred fifty individuals from the production, transmission and distribution segments of the natural gas industry who are knowledgeable with respect to the potential supply of natural gas.

The Committee functions independently but with the guidance and assistance of the Potential Gas Agency of the Colorado School of Mines. The Potential Gas Agency is supported by the American Gas Association.

The PGC and its Area Work Committees discuss matters and data that are confidential. Fulfillment of the objectives of the PGC cannot be realized without the availability and utilization of information of a highly confidential nature. It is, therefore, the policy of the PGC and its Work Committees that every member, observer and representative will respect such information and that there will be no disclosure of information or estimates, discussions, or other data, except as approved for release by the PGC.

A diagram of the organizational structure for the estimation of the potential supply of natural gas is shown in Figures 10 and 11. A detailed description of the membership and duties of the several committees and of the PGC is presented in the sections that follow.

Gas Supply Committee of the American Gas Association

The membership of the Gas Supply Committee consists of representatives of member companies of the American Gas Association selected by the Chairman of the Board and approved by the Board of Directors of the American Gas Association.

The scope of the Committee is to coordinate, motivate and make recommendations to the Board of American Gas Association as to the areas in which A.G.A. should become more active in the development of adequate gas supply for both short-term and long-term. In addition, the Committee undertakes special projects, where necessary, to evaluate industry gas supply programs. The Gas Supply Committee oversees the work of the Potential Gas Agency.

The primary duties and responsibilities of the Gas Supply Committee with relation to potential gas studies include the following:

a. Establishing policy and objectives.
b. Providing required financial support.
c. Maintaining liaison with industry and industry organizations.
d. Selecting the Potential Gas Agency.
e. Approving the appointment of the President-General Chairman and Regional Vice Presidents of the Potential Gas Committee by the Potential Gas Agency.
f. Appointing pipeline and distributor representatives to the Potential Gas Committee as may be necessary or advisable.
g. Appointing such other members and observers to the Potential Gas Committee as may benecessary or advisable.

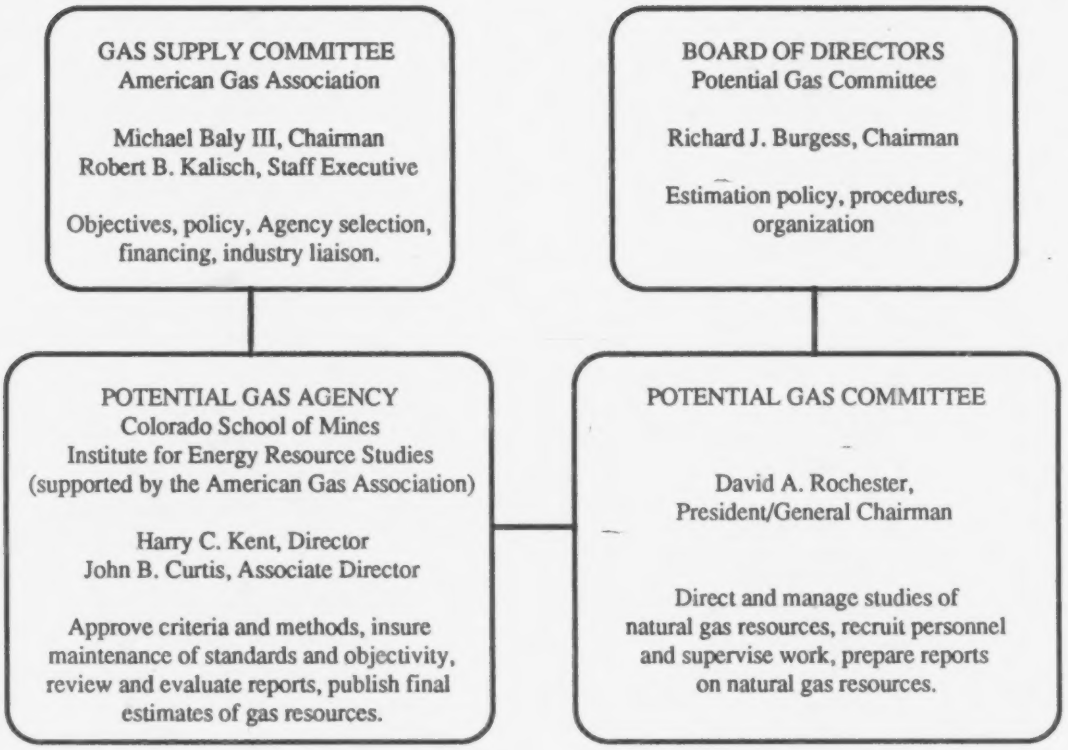
GAS SUPPLY COMMITTEE
American Gas Association
Michael Baly III, Chairman
Robert B. Kalisch, Staff Executive
Objectives, policy, Agency selection, financing, industry liaison.
BOARD OF DIRECTORS
Potential Gas Committee
Richard J. Burgess, Chairman
Estimation policy, procedures, organization
POTENTIAL GAS AGENCY
Colorado School of Mines
Institute for Energy Resource Studies
(supported by the American Gas Association)
Harry C. Kent, Director
John B. Curtis, Associate Director
Approve criteria and methods, insure maintenance of standards and objectivity, review and evaluate reports, publish final estimates of gas resources.
POTENTIAL GAS COMMITTEE
David A. Rochester, President/General Chairman
Direct and manage studies of natural gas resources, recruit personnel and supervise work, prepare reports on natural gas resources.

Figure 10. Organization of Potential Gas Resource Studies

h. Assisting in procurement of qualified manpower to staff properly the Potential Gas Committee and the Area Work Committees.

The Gas Supply Committee of the American Gas Association takes no part in the work or the deliberations of the Potential Gas Committee or its subcommittees. The Gas Supply Committee does not participate in the studies leading to the estimates of potential supply of natural gas, and it neither approves nor disapproves the definitions and procedures, the estimates, or the report.

Potential Gas Agency of the Colorado School of Mines

The Potential Gas Agency functions under the direction of the Vice President for Academic Affairs of the Colorado School of Mines. The School, with the approval of the Gas Supply Committee, appoints staff personnel to the Potential Gas Agency.

POTENTIAL GAS COMMITTEE

David A. Rochester, President/General Chairman
Richard J. Burgess, Chairman, Board of Directors
J. Scott Jenkins, Secretary
Billy D. Brown, Chairman, Editorial Committee

Under direction of Potential Gas Agency, outline study; establish criteria and methods; designate and instruct Area Work Committees; supervise, coordinate and compile estimates made by Work Committees.

Membership:

a) President/General Chairman and Regional Vice Presidents--appointed by Potential Gas Agency and approved by A.G.A. Gas Supply Committee.
b) Area Work Committee Members.
c) Potential Gas Agency Director, Ex-officio.
d) Technical Advisors and Honorary Technical Advisors.
e) A.G.A. staff—one voting representative.
f) Pipeline and Distributor representatives, designated by the Gas Supply Committee—voting representatives.
g) Observers from the federal government: Department of Energy, Energy Information Administration; Federal Energy Regulatory Commission; Department of Interior, Geological Survey, Bureau of Land Management, Minerals Management Service, Bureau of Mines; and such other government agencies as the Gas Supply Committee and the Potential Gas Agency shall approve—one nonvoting observer each, and alternates, if desired.
h) Gas Research Institute, Institute of Gas Technology, Natural Gas Supply Association, Electric Power Research Institute, Association of American State Geologists, Interstate Natural Gas Association of America, National Association of Regulatory Utilities Commissioners and Interstate Oil Compact Commission--one nonvoting observer each, and alternates, if desired.
i) Canadian natural gas industry--one observer each, and alternates, if desired.
j) Others appointed by the Gas Supply Committee and approved by the Potential Gas Agency.

AREA WORK COMMITTEES

EASTERN REGION

Mike H. Knobloch, Regional Vice President

Area	Chairman
Atlantic	James M. Wigal
North Central	William E. Mantek
Gulf Coast	Lee R. Tramel
Mid-Continent	Kenneth H. Dwight

WESTERN REGION

H.O. (Olie) Woodbury, Regional Vice President

Area	Chairman
Rocky Mountain	Marshall C. Crouch
Pacific	Peter D. Yu
Alaska	Richard Drumheller
Coalbed Methane	D. Keith Murray

Figure 11. Organization of Potential Gas Committee

The Potential Gas Agency is supported by the American Gas Association. The American Gas Association is free, however, to take independent views of the operations and the studies produced by the Agency and its committees. The Agency is charged with the maintenance of scientific standards and objectivity of studies and publishes the reports of the Potential Gas Committee. The Agency appoints the President/General Chairman and Regional Vice Presidents of the Potential Gas Committee, approves the appointment of members, representatives and observers to the Potential Gas Committee and the chairmen of all subcommittees.

The Potential Gas Agency includes the following:

a. A Director, appointed by and responsible to the Colorado School of Mines.

b. Such additional staff personnel as may be required.

c. Members of the faculty of the Colorado School of Mines or other qualified individuals who may, from time to time, provide such professional services as the Director of the Potential Gas Agency and the President/General Chairman of the Potential Gas Committee may determine necessary or desirable for discharging the duties of the Potential Gas Agency and the Potential Gas Committee.

The primary duties and responsibilities of the Potential Gas Agency include the following:

a. Approving criteria and methods established by the Potential Gas Committee, including protecting the confidentiality of Potential Gas Committee data.

b. Insuring maintenance of the highest scientific standards and objectivity in Potential Gas Committee studies and reports.

c. Reviewing and evaluating reports prepared by the Potential Gas Committee.

d. Publishing, distributing and publicizing reports of final estimates and other pertinent reports prepared by the Potential Gas Committee so as to assure the widest possible distribution and to promote understanding of them.

e. Further develop mutual understanding among the segments of the gas industry by helping the Gas Supply Committee unite the industry behind the potential gas studies.

f. Help improve industry-government relations in the public interest looking toward maximum acceptance and usefulness of potential gas studies.

g. Fulfill the professional obligation to publish technical papers concerning new techniques and knowledge gained.

h. Appointing President/General Chairman and Vice Presidents of Potential Gas Committee, with approval of Gas Supply Committee.

i. Approving appointment by Gas Supply Committee of other members, representatives and observers to the Potential Gas Committee.

j. Approving appointment of President/General Chairman of Potential Gas Committee, of Chairman of each Work Committee and chairmen of other committees.

k. Conduct the work of the Potential Gas Agency, in the public interest, in a manner which will enhance the stature of the Colorado School of Mines.

l. Adhere to the highest standards of objectivity.

The Colorado School of Mines may pursue other research, and individuals from the Agency may be involved in other research, consulting and preparation and publication of papers in their professional fields, so long as these activities do not involve a conflict of interest nor invalidate the objectivity of the Agency.

Potential Gas Committee

The Potential Gas Committee comprises members, representatives and observers from the producing, pipeline and distribution branches of the gas industry, together with observers from the American Gas Association, Department of Energy, Federal Energy Regulatory Commission, U.S. Geological Survey, National Association of Regulatory Utility Commissioners, Interstate Oil Compact Commission, U.S. Bureau of Mines, Gas Research Institute, Institute of Gas Technology, Association of American State Geologists, Electric Power Research Institute, Natural Gas Supply Association, Energy Information Administration, Interstate Natural Gas Association of America, Bureau of Land Management, Minerals Management Service and representatives from Canada.

The President/General Chairman of the Potential Gas Committee is assisted by the two Regional Vice Presidents and by a Board of Directors, composed of senior members of the Potential Gas Committee, including past chairmen. It is the function of the Board of Directors to advise the President/General Chairman on policy matters.

An Editorial Committee is charged with approving the content of the report of the Potential Gas Committee.

The Definitions and Procedures Committee has the responsibility of reviewing and recommending to the membership of the Potential Gas Committee any proposed changes in the definitions and procedures used in the estimation of potential gas resources.

Membership of the Potential Gas Committee specifically includes the following:

a. President/General Chairman of Potential Gas Committee.
b. Secretary of Potential Gas Committee.
c. Regional Vice Presidents and Assistant Vice Presidents.
d. Chairman and Vice Chairman of each Area Work Committee.
e. Chairman of Board of Directors.
f. Chairman of Editorial Committee.
g. Chairman of Committee on Definitions and Procedures.
h. Chairman of Time and Site Committee.
i. Director of the Potential Gas Agency, ex officio.
j. Observers from:
    - Association of American State Geologists
    - Electric Power Research Institute
    - Federal Energy Regulatory Commission
    - Gas Research Institute
    - Institute of Gas Technology
    - Interstate Natural Gas Association of America
    - Interstate Oil Compact Commission
    - Minerals Management Service
    - National Association of Regulatory Utility Commissioners
    - Natural Gas Supply Association
    - U. S. Bureau of Land Management
    - U. S. Bureau of Mines
    - U. S. Department of Energy, Energy Information Administration
    - U. S. Geological Survey
k. Representatives from the natural gas pipeline industry.
l. Representatives from the natural gas distribution industry.
m. Representative from the American Gas Association.
n. Observers from the Canadian natural gas industry.
o. Technical Advisors and Honorary Technical Advisors.
p. Representatives and observers from other organizations may be recommended for appointment by the Potential Gas Agency Director and approved by the Gas Supply Committee.

All members of the Potential Gas Committee, except those specifically designated as observers, are considered as voting members of the Potential Gas Committee. Observers are invited and encouraged to participate in discussion of items brought before the Potential Gas Committee but do not have a vote in the determination of policy and procedure. Alternates to representatives and observers may be appointed.

Candidates for Committee President/General Chairman and Vice Presidents normally will be geologists or persons with geology background from the academic community, pipelines, independent firms, gas utilities or producing companies. Retired or semiretired gas industry people are not excluded from consideration.

Officers of the Potential Gas Committee and Area Work Committees are appointed as outlined in the Organizational Chart (Figure 11). Normally, they serve for a period of one report. They are eligible for reappointment, however, for one additional report period. In calculating eligibility for reappointment, a partial term of office shall not be counted. This policy shall not operate to disqualify a member from longer service by reason of elevation in the organization. In other words, the two-term limitation shall apply to each position held, considering each membership or officership on a work committee or top committee as a separate position.

All officers, regional vice presidents and the pipeline and distributor representatives appointed by the American Gas Association Gas Supply Committee shall be subject to the two-report limit. Exceptions must be recommended by the appropriate Committee Chairman and the Potential Gas Agency Director and approved by the American Gas Association Gas Supply Committee.

Technical Advisors include persons who have special knowledge of the occurrence of natural gas or the natural gas industry and whose expert advice will contribute to the successful performance of the Committee's assignments. Past Chairmen of Work Areas and Past Regional Vice Presidents of the Potential Gas Committee will be appointed as Technical Advisors if they are willing to continue to participate in the work of the Committee. The appointment of Technical Advisors is approved by the Gas Supply Committee upon recommendation by the Potential Gas Agency Director. Technical Advisors are appointed for the preparation of a specific PGC report. Their appointment may be continued indefinitely but is subject to review and approval at the time of organization of the Potential Gas Committee for each succeeding report.

The designation of Honorary Technical Advisor may be given to such persons as have performed exceptional service to the Potential Gas Committee and whose continued participation and advice are desirable for the continued successful operation of the Committee. Honorary Technical Advisors are permanent voting members; their appointment is recommended by the Board of Directors and approved by the Potential Gas Agency Director and the Gas Supply Committee.

Observers from sponsoring associations, governmental agencies and other cooperating groups serve at the discretion of these organizations and are not subject to the two-report policy.

The primary duties and responsibilities of the Potential Gas Committee include the following:

a. Outlining the scope and coverage of the estimates of potential natural gas supply.
b. Establishing criteria and methods for estimation of potential natural gas supply and other pertinent studies.
c. Designating Work Areas and Special Projects.
d. Appointing the Chairman of each Area Work Committee (by action of President/General Chairman of Potential Gas Committee).
e. Approving appointment of other members of each Area Work Committee who are appointed by the Chairman of each Area Work Committee (by action of President/General Chairman of Potential Gas Committee).
f. Instructing Area Work Committees.
g. Supervising, coordinating, advising, reviewing, evaluating, approving and compiling estimates and such other assignments as may be given to committees.
h. Preparing reports of final estimates and such other reports as may be pertinent.
i. Submitting reports of final estimates and other pertinent reports to the Potential Gas Agency and counseling with Director regarding publication and distribution of such report.

Area Work Committees

Seven Area Work Committees are the backbone of the Potential Gas Committee. Each of the Work Committees has the responsibility of developing an estimate of the potential supply of natural gas in a particular part of the United States. Following the system long used by the petroleum industry, each Area Work Committee is assigned geologically significant areas (without specific regard to state lines) in which the Committee members have expert working knowledge. These Committee members with their fund of information (often confidential), are the source of knowledge and judgment for estimating the undiscovered gas supply in each area. Because geologic rather than geographic divisions are used, publication of estimates by individual states is not feasible.

The membership of Area Work Committees consists of employees and consultants associated with the producing, pipeline and distribution segments of the gas industry—as well as qualified personnel from State and Federal Agencies and educational institutions.

For administrative purposes, the Area Work Committees are grouped together in two regions: Eastern and Western. Each of these regions is supervised by a Regional Vice President who coordinates activities of the Area Work Committees within his jurisdiction and works with the Potential Gas Committee President-General Chairman in order to assure that there is an open flow of communication in both directions, and that the established techniques for resource estimation are being followed by the Area Work Committees.

Membership of Area Work Committees includes the following:

a. Chairman of each Area Work Committee.
b. An appropriate number of qualified working members deemed necessary by the Chairman of each Work Committee to ensure the most objective estimates of potential supply of natural gas in the respective area assigned. Work Committee members are individuals from the natural gas and oil industries and other individuals who are qualified by their knowledge and experience to make estimates of potential supply of natural gas. The individuals are selected for each area because they have a close, working knowledge in all aspects of natural gas exploration and production.
c. At least one qualified representative on each Area Work Committee from the natural gas pipeline industry, appointed by the Gas Supply Committee. (This requirement is currently waived for the Alaska Committee.)
d. At least one qualified representative on each Area Work Committee from the natural gas distribution industry, appointed by the Gas Supply Committee. (This requirement is waived for the Alaska Committee.)

The Chairman and Vice Chairman of each Area Work Committee are subject to the two-report limit. Exceptions must be recommended by the Regional Vice President, approved by the Potential Gas Committee President/General Chairman and the Potential Gas Agency Director, and reported to the Gas Supply Committee, and only after receiving a clearance letter from the member's employer.

Other members of the Area Work Committees, appointed by the Area Chairman, will normally participate in the preparation of two successive reports. Service beyond the preparation of two reports may be continued if necessary to maintain adequate expertise and continuity on the Area Work Committee. Continuation of service beyond two reports must be recommended by the Area Chairman and approved by the Regional Vice President, the Potential Gas Committee President/General Chairman, and the Potential Gas Agency Director.

The primary duties and responsibilities of Area Work Committees include the following:

a. Appointing appropriate number of qualified working members to insure proper representation of various sectors of the industry and objectivity for the best estimates of potential supply of natural gas for assigned areas (by action of Chairman of each Area Work Committee).
b. Estimating quantity of potential supply of natural gas in working areas designated by the Potential Gas Committee pursuant to the guidelines and parameters established by the Potential Gas Committee, and approved by the Potential Gas

Agency, and such other studies as may be assigned by the Potential Gas Committee.

c. Performing such other assignments as may be made in the respective area assigned by the Potential Gas Committee regarding such estimate.

Each member of each Area Work Committee will submit his estimates of potential supply of natural gas and such other assignments as may be given to him in his assigned subarea to the Chairman and other members of his committee for review, evaluation and approval.

The Coalbed Methane Work Committee is organized along the same lines as the Area Work Committees, with a Vice Chairman assigned to the Western and Eastern Regions.

Since the type and quantity of available information upon which to base estimates of potential natural gas supply vary widely from area to area, the Area Work Committee members use varied approaches in making their estimates. In as much as the individual members work with private information obtained on a confidential basis from many sources, their working papers are not revealed in detail to anyone, including other members of the same Area Work Committee or others in the Potential Gas Committee. Without such confidential information, the Potential Gas Committee could not perform its task; therefore, each member, observer or representative of the Work Committees is aware of and must respect the confidential nature of the data made available to him and of the estimates and other assignments prepared or reviewed by the Area Work Committees and the Potential Gas Committee.

Standing Committees of the Potential Gas Committee

Board of Directors

The Board of Directors shall serve as the administrative coordinating committee for the Potential Gas Committee. It shall consider and discuss any matters of policy brought to its attention and shall make recommendations to the Potential Gas Committee regarding changes in policy. It shall act on behalf of the Potential Gas Committee on matters of urgency which arise between regularly scheduled meetings of the Potential Gas Committee. It may also be empowered to act on behalf of the Potential Gas Committee on matters designated by the Potential Gas Committee. At such times as vacancies occur in the following offices, the Board of Directors shall either act as a nominating committee to recommend suitable candidates or appoint a nominating committee from among its membership: PGC President/General Chairman, Regional Vice Presidents, Secretary of the PGC and Chairman of the Board of Directors.

Chairmen of PGC standing committees, with the exception of the Board of Directors, will be appointed by the PGC President/General Chairman, subject to approval by the Board of Directors. All actions of the Board of Directors will be reported to the membership of the Potential Gas Committee at their next regularly scheduled meeting and shall be subject to review and approval by the Potential Gas Committee.

Membership: Chairman, elected from the membership of the Potential Gas Committee by the voting members of the PGC at a regular meeting. Nominations for Chairman will be made by the Board of Directors and nominations will also be received from the floor. Normally, the Chairman will be elected at the fall meeting following publication of the biennial PGC report and will serve for two years. Vacancies will be filled by election at the next regular PGC meeting, following the same procedure and a Chairman so elected will serve for the remainder of the unexpired term. In the absence of the elected Chairman, the President/General Chairman of the Potential Gas Committee will serve as Chairman of the Board of Directors.

The following are ex officio voting members: PGC President/General Chairman, PGC Regional Vice Presidents, Secretary of the PGC, Potential Gas Agency Director, Chairmen of Standing Committees, representatives appointed to the PGC from the natural gas pipeline and natural gas distribution industries, representative from the Canadian gas industry, representative from the American Gas Association.

In addition, a maximum of five voting Technical Advisors may be appointed by the Potential Gas Committee President/General Chairman, subject to approval by the Potential Gas Agency Director.

Editorial Committee

The Editorial Committee will review and approve the editorial content and format of PGC reports. They will work closely with the Potential Gas Agency in the publication of all official publications of the Potential Gas Committee.

Membership: Chairman, appointed by the Potential Gas Committee President/General Chairman, and approved by the Board of Directors. Six members of the Potential Gas Committee, appointed by the Editorial Committee Chairman, with approval of the PGC President/General Chairman plus the following ex officio members: PGC President/General Chairman, Potential Gas Agency Director and Associate Director, Chairman of the Board of Directors.

Administrative Committee

This Committee has the responsibility of assisting and advising the Area Chairmen and Regional Vice Presidents in identifying and recruiting qualified members for the Potential Gas Committee and advising the Board of Directors and the Potential Gas Committee membership concerning record keeping.

Membership: Chairman, appointed by the PGC President/General Chairman and approved by the Board of Directors. Other members are appointed by the Chairman of the Administrative Committee, with approval of the PGC President/General Chairman plus the following ex officio members: PGC President/General Chairman, Potential Gas Agency Director and Associate Director, Chairman of the Board of Directors.

Committee on Definitions and Procedures

This Committee has the responsibility of reviewing and recommending to the membership of the Potential Gas Committee any proposed changes in the definitions and procedures used in the estimation of potential gas resources. Proposals to be reviewed by this Committee may be submitted by any member of the Potential Gas Committee. The Committee will further review estimates of potential gas resources made by other organizations which come to the attention of the Committee and may, from time to time, as deemed appropriate, prepare publications dealing with the comparison of the work of the Potential Gas Committee with that of other organizations. The Committee on Definitions and Procedures will also serve as liaison with the US Geological Survey Resource Appraisal Group and other such organizations as are involved in the work of estimation of potential gas resources.

Membership: Chairman, appointed by the PGC President/General Chairman and approved by the Board of Directors. Four members of the Potential Gas Committee, appointed by the Chairman of the Committee on Definitions and Procedures, with approval of the PGC President/General Chairman plus the following ex officio members: PGC President/General Chairman, Potential Gas Agency Director and Associate Director, Chairman of the Board of Directors.

Time and Site Committee

This Committee will select an appropriate location and date for each national PGC meeting which will serve best the needs of the Committee. Once the site and date of each meeting have been selected by the Committee, the Potential Gas Agency will be charged with the responsibility of completing the arrangements for the meeting. The Time and Site Committee will also coordinate any regional meetings which are scheduled by Regional Vice Presidents in order that the dates of such meetings shall not be in conflict.

Membership: Chairman, appointed by the PGC President/General Chairman and approved by the Board of Directors. Three members of the Potential Gas Committee, appointed by the Chairman of the Time and Site Committee and approved by the PGC President/General Chairman plus the following ex officio members: Regional Vice Presidents, PGC President/General Chairman and Potential Gas Agency Director.

Communications

Communication Between Committees

The formal channel of communication shall be from the Area Work Committees to the Potential Gas Committee to the Potential Gas Agency to the American Gas Association Gas Supply Committee and vice versa.

Public Communication

Members of the Potential Gas Agency, the Potential Gas Committee and the Area Work Committees are encouraged to publicize and explain their work. These efforts should be limited to explaining the methodology used, comparative methodology and the strengths and limitations of the work. When acting as spokesmen for the Committee, members shall refrain from interpreting study results in terms of national policy needs or required industry incentives. Members who are called upon to make talks and write papers on behalf of the Committee should submit texts to the Potential Gas Agency for comment and policy review.

MEMBERSHIP OF THE POTENTIAL GAS AGENCY AND POTENTIAL GAS COMMITTEE

POTENTIAL GAS AGENCY

Harry C. Kent, Executive Director
John B. Curtis, Associate Director
Joseph J. Finney, Associate Director
Sharon J. Kirts, Staff Assistant

POTENTIAL GAS COMMITTEE

David A. Rochester, President/General Chairman
Mike H. Knobloch, Vice President, Eastern Region
H. O. (Olie) Woodbury, Vice President, Western Region
J. Scott Jenkins, Secretary

Board of Directors

Richard J. Burgess, Chairman

Donald W. Axford
Billy D. Brown
John B. Curtis
A. M. Derrick, Jr.
Dan B. Grubb
Robert D. Habbit
John D. Haun
J.C. Herrington
Robert E. Hodge
J. Scott Jenkins
Robert B. Kalisch
Harry C. Kent
Sharon J. Kirts
Mike H. Knobloch
Jack Lewis
William E. Mantek
Jeffery V. Morris
D. Keith Murray
David A. Rochester
Richard J. Snyder
H. O. (Olie) Woodbury

Editorial Committee

Billy D. Brown, Chairman

A. M. Derrick, Jr.
J. Scott Jenkins
Mike H. Knobloch
William E. Mantek
ex officio:
Richard J. Burgess
John B. Curtis
Harry C. Kent
David A. Rochester

Committee on Definitions and Procedures

John D. Haun, Chairman
Jack Lewis, Vice Chairman

Donald E. Hallinger
Richard Snyder

ex officio:
Richard J. Burgess
John B. Curtis

Harry C. Kent
David A. Rochester

Administrative Committee

Dan B. Grubb, Chairman
Jack Lewis, Vice Chairman

J. C. Herrington
Mike H. Knobloch
H. O. (Olie) Woodbury

ex officio:
Richard J. Burgess
John B. Curtis

Harry C. Kent
David A. Rochester

Time and Site Committee

J. C. Herrington, Chairman

ex officio: Richard J. Burgess
Harry C. Kent

Mike H. Knobloch
David A. Rochester

H. O. (Olie) Woodbury

AREA WORK COMMITTEES

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** Gas distributors representative.

Plate 1
POTENTIAL GAS COMMITTEE
NATURAL GAS MAP OF THE UNITED STATES
December 31, 1988

- AREAS OF GAS PRODUCTION INCLUDING GAS ASSOCIATED WITH OIL
- AREAS IN WHICH SEDIMENTARY ROCKS ARE EXPOSED AT THE SURFACE OR ARE PRESENT AT DEPTH AND COVERED AT THE SURFACE BY EXTRUSIVE IGNEOUS ROCKS
- AREAS IN WHICH INTRUSIVE IGNEOUS ROCKS OR METAMORPHIC ROCKS ARE EXPOSED AT THE SURFACE
- LIMITS OF SEDIMENTARY BASINS AS RECOGNIZED BY THE POTENTIAL GAS COMMITTEE, DASHED WHERE INFERRED
- CONTOUR LINE INDICATING THICKNESS OF SEDIMENTS

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Western Thrust Belt

The Western Thrust Belt, especially the central portion which is located along the Wyoming-Idaho border, has become a major target for exploration. Significant gas fields have been discovered in southwestern Wyoming and northern Utah. While the eastern boundary of this belt is fairly well defined by the limits of thrust faults, the western boundary is much more nebulous. Some interpretations extend the Western Thrust Belt southeastward from southern Nevada through Arizona, southeastern New Mexico, westernmost Texas and into Mexico. At the present time, the only areas within the Thrust Belt in which estimates of potential resources of natural gas have been made are the northern, central and southern portions indicated on the map. Because of lack of positive confirmation of the extension of the Thrust Belt south of Utah and the lack of data on potential source rocks, reservoir rocks and trapping mechanisms, no estimate of any potential resource of natural gas has been made for this area.

- Exposed Sediments
- Concealed Sediments

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Mid-Continent Rift

Exploration interest has been focused on the Mid-Continent Rift Zone which traverses the North Central Area from northeastern Kansas and Nebraska to northern Minnesota and Wisconsin. The feature is defined primarily on the basis of geophysical data. It is postulated that considerable thicknesses of sedimentary rocks were deposited along this tectonic trend in elongate fault-block basins which may contain potential reservoir and source rocks. The faulting which is associated with the Rift Zone may have originated in Precambrian time and have continued to affect Paleozoic sedimentation as well.

- Exposed Sediments
- Concealed Sediments

Eastern Thrust Belt

Geophysical data and resulting exploratory activity have led to the interpretation of an Eastern Thrust Belt extending from Canada southward into Georgia and Alabama. In the western portion of this belt, sedimentary rocks are exposed at the surface. In the eastern portion, sedimentary rocks are believed to exist beneath metamorphic rocks. Preliminary estimates of natural gas resources for the Eastern Thrust Belt are included in the estimates reported for the Atlantic Area.

Lower Mobile Bay Norphlet Play

Significant natural gas has been discovered in Lower Mobile Bay and the immediately adjacent federal waters in an eolian facies of the Norphlet Formation. Producing depths exceed 20,000 feet. Fields found to date are estimated to range in size from 200 Bcf to in excess of 1 Tcf. Lateral extent of the play is not completely known, but estimates of the resource potential have been included in the estimates for provinces P-300 and P-930.

- Exposed Sediments
- Concealed Sediments

P-960-961 PACIFIC OFFSHORE (0-200m)SHELF (200-1000m)SLOPE
P-600 W-ASHINGTON
P-610 EASTERN COLUMBIA BASIN
OREGON-WASHINGTON COASTAL BASINS-OKANOGAN PROVINCE
SNAKE RIVER BASIN P-580
SWEETGRASS ARCH-CENTRAL MONTANA UPLIFT
Northern Thrust Belt
P-570
P-575 MONTANA FOLDED BELT
P-500 WILLISTON BASIN
ROCKY
P-515 BIG HORN BASIN
Central Thrust Belt
P-510 POWDER RIVER BASIN
WIND RIVER BASIN
P-520
P-590 WYOMING-UTAH-IDAHO THRUST BELT
GREATER GREEN RIVER BASIN, HANNA-LARAMIE BASINS
P-530
P-535
DENVER BASIN, CHADRON ARCH, LAS ANIMAS ARCH
P-400 CENTRAL KANSAS UPLIFT, SALINA BASIN, NEMAHA ANTICLINE, SEDGWICK BASIN
P-240 WISCONSIN ARCH, SIOUX UPLIFT, IOWA SHELF
NORTH
P-300 MICHIGAN BASIN
Midcontinent Rift
P-260 FOREST CITY BASIN, CHEROKEE BASIN
P-220 ILLINOIS BASIN
P-250 LINCOLN ANTICLINE, OZARK UPLIFT
CENTRAL
P-210 CINCINNATI ARCH
P-120 APPALACHIAN BASIN
NEW BRUNSWICK
NEW ENGLAND PROVINCE, ADIRONDACK UPLIFT P-100
P-910-911 ATLANTIC OFFSHORE (0-200m)SHELF (200-1000m)SLOPE
ATLANTIC
PIEDMONT-BLUE RIDGE PROVINCE P-130
ATLANTIC COASTAL BASIN P-110
P-230 UPPER MISSISSIPPI EMBAYMENT
P-150 BLACK WARRIOR BASIN
P-410 ARKOMA BASIN
SACRAMENTO BASIN
GREAT BASIN, SIERRA NEVADA, KLAMATH MTNS.-SOUTHERN OREGON P-620
PACIFIC
P-640
P-650 SAN JOAQUIN BASIN
CALIFORNIA COASTAL BASINS P-660
P-630 SOUTHEASTERN CALIFORNIA BASINS
MOUNTAIN
P-565 PLATEAU PROVINCE, BLACK MESA BASIN
P-545
SAN LUIS BASIN, SAN JUAN MTNS., SIERRA GRANDE UPLIFT, LAS VEGAS-RATON BASIN
SAN JUAN BASIN P-555
P-540 UINTA-PICEANCE BASIN, PARK BASINS, EAGLE BASIN
Southern Thrust Belt
PARADOX BASIN P-550
P-560 SOUTHERN BASIN & RANGE PROVINCE
PALO DURO BASIN, WICHITA-AMARILLO PLATFORM P-420
P-430 FT. WORTH BASIN, BEND ARCH, MARFA BASIN
CONTINENT
P-320 EAST TEXAS BASIN
GULF
LOUISIANA-MISSISSIPPI-ALABAMA SALT BASINS
COAST
MISSISSIPPI P-300
SOUTH GEORGIA-PENINSULAR FLORIDA SEDIMENTARY PROVINCE
P-140
LOUISIANA GULF COAST BASIN P-310
P-930-931 EASTERN GULF COAST OFFSHORE (200-1000m)SLOPE (0-200m)SHELF
TEXAS GULF COAST BASIN P-360
TEXAS OFFSHORE P-940-941 (0-200m)SHELF (200-1000m)SLOPE
P-935-936 LOUISIANA OFFSHORE (0-200m)SHELF (200-1000m)SLOPE
P-945 GULF of MEXICO OUTER CONTINENTAL SLOPE
P-915-916 WEST FLORIDA OFFSHORE (0-200m)SHELF (200-1000m)SLOPE
BALTIMORE CANYON TROUGH
BLAKE PLATEAU
GEORGES BANK BASIN

R8065-1

Plate 2
POTENTIAL GAS COMMITTEE
NATURAL GAS MAP OF ALASKA
December 31, 1986

1986 ESTIMATED POTENTIAL RESOURCES OF NATURAL GAS IN ALASKA
(Trillion cubic feet – most likely estimates)

PROBABLE – 8.99 POSSIBLE – 29.10 SPECULATIVE – 80.69

- AREAS OF GAS PRODUCTION INCLUDING GAS ASSOCIATED WITH OIL
- AREAS IN WHICH SEDIMENTARY ROCKS ARE EXPOSED AT THE SURFACE OR ARE PRESENT AT DEPTH AND COVERED AT THE SURFACE BY EXTRUSIVE IGNEOUS ROCKS
- AREAS IN WHICH INTRUSIVE IGNEOUS ROCKS OR METAMORPHIC ROCKS ARE EXPOSED AT THE SURFACE
- LIMITS OF SEDIMENTARY BASINS AS RECOGNIZED BY THE POTENTIAL GAS COMMITTEE. DASHED WHERE INFERRED
- SEDIMENTARY BASINS BELIEVED NOT TO HAVE POTENTIAL FOR NATURAL GAS
- CONTOUR LINE INDICATING THICKNESS OF SEDIMENTS

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50 0 50 100 150 MILES
50 0 50 100 150 KILOMETERS

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P-701 NORTH SLOPE PROVINCE
P-702 BROOKS RANGE PROVINCE
P-703 YUKON FLATS-KANDIK BASIN
P-704 ALASKA INTERIOR BASINS
P-705 NORTHERN GULF OF ALASKA PROVINCE ONSHORE
P-706 SOUTHEASTERN ALASKA PROVINCE
P-707 COOK INLET/SUSITNA PROVINCE ONSHORE
P-708 ALASKA PENINSULA-SHUMAGIN ONSHORE
P-709 ALASKA PENINSULA-BRISTOL BAY ONSHORE
P-710 ALEUTIAN ISLANDS
P-971 BEAUFORT SEA SHELF (0-200m)
P-972 BEAUFORT SEA SLOPE (200-1000m)
P-973 CHUKCHI SHELF (0-200m)
P-974 NORTON BASIN
P-975 HOPE BASIN
P-979 ST. MATTHEW-BETHEL BASIN SHELF (0-200m)
P-980 SOUTHWEST BERING SEA SLOPE (1000m)
P-981 NAVARIN BASIN SHELF (0-200m)
P-982 NAVARIN BASIN SLOPE (200-1000m)
P-983 ST. GEORGE BASIN SHELF (0-200m)
P-984 ST. GEORGE BASIN SLOPE (200-1000m)
P-985 BRISTOL BAY BASIN SHELF (0-200m)
P-987 SHUMAGIN-KODIAK SHELF (0-200m)
P-988 SHUMAGIN-KODIAK SLOPE (200-1000m)
P-989 ALEUTIAN SHELF (0-200m)
P-990 ALEUTIAN SLOPE (200-1000)
P-991 NORTHERN GULF OF ALASKA SHELF (0-200m)
P-992 NORTHERN GULF OF ALASKA SLOPE (200-1000m)
P-993 SOUTHEASTERN ALASKA SHELF (0-200m)
P-994 SOUTHEASTERN ALASKA SLOPE (200-1000m)
P-995 COOK INLET BASIN OFFSHORE

ARCTIC OCEAN
BEAUFORT SEA
CHUKCHI SEA
BERING SEA
BRISTOL BAY
GULF OF ALASKA
PACIFIC OCEAN
U.S.S.R.
CANADA
U.S.A.
YUKON TERRITORY
NORTHWEST TERRITORIES
BRITISH COLUMBIA
BROOKS RANGE
ENDICOTT MTNS.
PHILIP SMITH MOUNTAINS
BRITISH MOUNTAINS
RICHARDSON MOUNTAINS
MACKENZIE MOUNTAINS
FRANKLIN MTNS.
ROCKY MOUNTAINS
CASSIAR MOUNTAINS
ST. ELIAS MOUNTAINS
COAST MOUNTAINS
ALASKA RANGE
WRANGELL MTNS.
CHUGACH MOUNTAINS
KUSKOKWIM MTNS.
SEWARD PENINSULA
ALEUTIAN ISLANDS
NEAR ISLANDS
RAT ISLANDS
ANDREANOF ISLANDS
PRINCE OF WALES ISLAND
QUEEN CHARLOTTE ISLANDS
HECATE STRAIT
DIXON ENTRANCE
MACKENZIE BAY
POINT BARROW
POINT HOPE
ICY CAPE
ST. LAWRENCE ISLAND
ST. MATTHEW ISLAND
NUNIVAK ISLAND
ST. PAUL ISLAND
ST. GEORGE ISLAND
UMNAK ISLAND
UNALASKA ISLAND
UNIMAK ISLAND
TRINITY ISLANDS
CHIRIKOF ISLAND
KODIAK ISLAND
AFOGNAK ISLAND
STEVENSON ISLAND
MONTAGUE ISLAND
BARANOF ISLAND
ATTU ISLAND
AGATTU ISLAND
KISKA ISLAND
AMCHITKA ISLAND
TANAGA ISLAND
ADAK ISLAND
ATKA ISLAND
AMLIA ISLAND
SEGUAM ISLAND
BERING STRAIT
NORTON SOUND
KOTZEBUE SOUND
KUSKOKWIM BAY
NORTON BASIN
HOPE BASIN
BAIRD MTNS.
KOYUKUK BASIN
YUKON FLATS BASIN
KANDIK BASIN
TANANA BASIN
COPPER RIVER BASIN
KUSKOKWIM BASIN
BETHEL BASIN
SHUMAGIN BASIN
SANAK BASIN
ALBATROSS BASIN
KODIAK BASIN
SHELIKOF STRAIT
SHELIKOF SHELF
ALASKA PENINSULA
TERTIARY PROVINCE
NORTHERN GULF OF ALASKA
MIDDLETON BASIN
YAKATAGA BASIN
YAKUTAT BASIN
EASTERN GULF OF ALASKA SHELF
PRINCE WILLIAM SOUND
COLVILLE RIVER
YUKON RIVER
PELLY RIVER
MACKENZIE RIVER
200 METERS
1000 METERS